This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

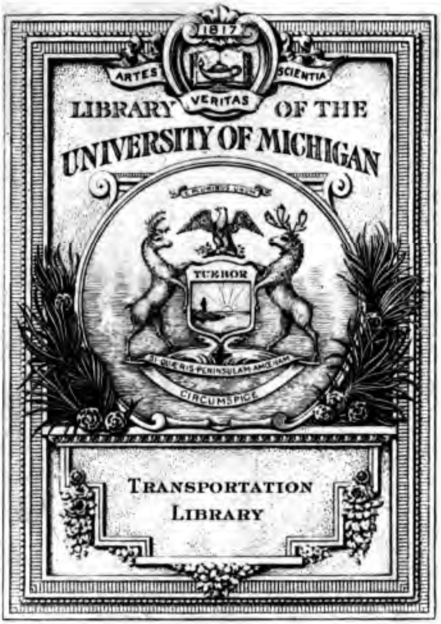
+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`

.T94


1817
ARTES
VERITAS
SCIENTIA
LIBRARY OF THE
UNIVERSITY OF MICHIGAN
E PLURIBUS UNUM
TUEBOR
SI QUÆRIS PENINSULAM AMŒNAM
CIRCUMSPICE
TRANSPORTATION
LIBRARY

Transportatio
Library
TF
692,
T94

Chester '90

AN ESSAY

ON THE

AIR-PUMP AND ATMOSPHERIC RAILWAY;

CONTAINING FORMULÆ AND RULES

FOR

CALCULATING THE VARIOUS QUANTITIES CONTAINED IN MR.
ROBERT STEPHENSON'S REPORT ON ATMOSPHERIC
PROPULSION, FOR THE DIRECTORS OF THE
CHESTER AND HOLYHEAD RAILWAY
COMPANY.

BY WILLIAM TURNBULL,

AUTHOR OF A TREATISE ON THE STRENGTH OF CAST IRON, ETC.

LONDON:
JOHN WILLIAMS AND CO., 141, STRAND.
1847.

J Sam. Jermyn

Bk no 95

LONDON:
DRURY, PRINTER, XXXI, BARTLETT'S BUILDINGS, HOLBORN.

Eling Transportation Lib.
-6-36

Mechanics' Institute.

G//-17-44

PREFACE.

THIS little work, in as far as the author's knowledge extends, is the first of the kind that has ever been composed on the subject. The principles of the air-pump have frequently been investigated, and are consequently well known to mathematical experimentalists; but the application to the propulsion of trains on a railway is a recent achievement, involving theories and calculations which had not previously been sufficiently considered, and are therefore but little understood by those who have the most occasion to employ them.

The present undertaking was suggested by reading Robert Stephenson's masterly and elaborate report on the atmospheric system of propulsion, as addressed to the directors of the Chester and Holyhead Railway Company. The writer's attention was first directed to this report by Mr. J. Bourne, the then Editor of the Artizan, who a few years ago supplied him with a copy of it, for the purpose of assisting in drawing up some papers on the subject for insertion in that periodical; but on examining the performance here alluded to, which bears the traces of a master hand on every page of it, considerable difficulty arose in discovering the principles from which many of the tabulated results had been deduced, and this difficulty was considerably enhanced, in consequence of its being the first occasion in which the author's attention had ever been directed to enquiries of this nature. This he candidly acknowledges; for notwithstanding his extensive experience in the way of computation and theoretical research, nothing of a pneumatic character had previously been proposed for his consideration, nor had he ever given his mind particularly to the subject, as a branch of study possessing anything peculiarly interesting or seductive.

It may be true that the difficulties here alluded to did not present themselves to every reader of the report; but there are many of the younger class of engineers, and even of those of higher standing and pretensions, who would, in several instances, find themselves sadly puzzled, if it were required of them to point out by what means some of the tabulated results had been obtained. It probably did not occur to them to enquire into the matter, the subject being apparently so simple in itself that they would most likely pass over the scientific part of the performance, without concerning themselves about the principles of calculation, and proceed immediately to the comparison, which was to uphold or condemn the system for which the trials had been instituted.

Such, however, was not the motive of the individual who now offers his labours to the public; his object was to consider the subject scientifically, for the purpose, as above stated, of supplying articles for publication in the Artizan, being at the time under a weekly engagement with the proprietors of that periodical,—in the pages of which many of his contributions are to be found, but without name or signature of any kind whatever, and therefore unrecognizable otherwise than by the nature of the subjects, and the peculiarity of the style in which they are written.

It was in thus qualifying himself for the task assigned to him, that the author of this performance first entertained the idea of drawing up a work of the kind; being naturally led to suppose that the same difficulties which he had himself encountered in reading the report, would present themselves to others who might feel disposed to trace the subject to its principles. It was thus the thought occurred to him that it might be useful to the young engineer, and to others connected with the various departments of practical mechanics, if the several formulæ and rules which bear upon the subject were brought together and published as an independent work, entirely distinct from any other branch of physical science whatever.

The design, however, was abandoned, in consequence of the termination of the Author's en-

Pa
Table of formulæ 42, 4
Atmospheric Railway 4
Mr. Pim's remarks on ditto . . . .
Description of the apparatus 46, 4
Mr. Stephenson's report alluded to . . . . . .
Mr. Stephenson's and Mr. Bergin's experiments . .
Table of experimental results . . . .
Directors' disregard for the results of theory . . .
The case different with young Engineers and general readers 53,
Calculation of the densities of the air . . . .
Calculated leakages compared with experiment . 57,
Table of falls in the vacuum gauge . . . . . .
Calculation of the corresponding densities . . .
" for the rate of leakage 66,
" for the area of the apertures of influx . 69,
" for the effect of leakage 73,
Intimation of another method of calculating the same effect
Table of observed and computed results . . . .
Number of strokes of the air-pump computed . . 75,
Messrs. Clarke and Varley's elastic railway tube . .
Diagram illustrative of ditto . . . .
Transverse vertical section showing the manner in which the side bars are supported . . . .
Transverse vertical section through the tube and rollers .
Metallic air-tight joint . . . .
Mr. George Medhurst's anticipations on Atmospheric propulsion . . . .
Answers to the unresolved examples . . . . .

AN

ESSAY ON THE AIR-PUMP

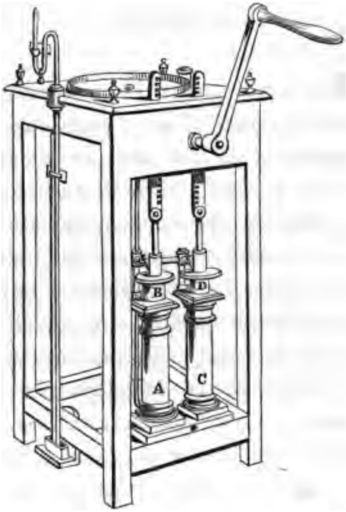
AND

ATMOSPHERIC RAILWAY.

IN order to form a correct and comprehensive notion of the nature and operation of an atmospheric railway, it becomes necessary in the first place, to possess a perfect knowledge of the air-pump, since that is the chief agent employed in effecting the vacuum, against which the pressure of the atmosphere operates to produce motion by this very ingenious and novel mode of transit.

The air-pump is an apparatus by which the air is extracted from close vessels. It was invented by Otto Guericke, a gentleman of Magdeburg in Germany, about the middle of the seventeenth century, and marks a very important era in the progress of the physical sciences; but in consequence of its recent application to the production of transit on a railway, it has acquired a degree of interest which it did not formerly possess, and an importance which had not previously been awarded to it.

This apparatus has undergone many changes in the progress of mechanical improvement; but as it is now constructed, it consists of two cylinders, A B and C D, generally of the same size, and bored with the utmost degree of precision. These cylinders are fitted with air-tight pistons, which are alternately elevated and depressed by means of rack-work, the one ascending while the other descends.



At A and C, the lower or inferior extremities of the cylinders or barrels, are valves opening downwards, and at B and D are apertures or orifices communicating with he vessel from which the air is to be extracted; which essel is generally known by the name of the *Receiver*.

On the ascent of the piston in the cylinder or barrel B, a vacuum is formed in the space beneath it, the alve at A being closed by the pressure of the external ir, and when the piston has ascended above the aperure or orifice at B, a communication is opened between he vacuum and the receiver or vessel from which the ir is to be extracted; the air then flows from the reeiver into the vacuous space, until the whole has acuired a uniform density, when the influx ceases.

But on the return downwards of the piston the air hich now occupies the space between A and B, or that hich was permitted to flow from the receiver, is comressed until it acquires a sufficient degree of elasticity o force open the valve at A against the pressure of the xternal air; when this has been effected, the air within he cylinder or barrel will be expelled, and when the pison is again drawn up above the orifice or aperture at B, he valve at A is shut by the pressure from without, and he space between A and B is filled with air from the reeiver as before, which is again expelled by the descent f the piston, and thus another exhaustion takes place. y pursuing this process of alternately elevating and epressing the piston, the air is ultimately exhausted om the receiver, or at least rarefied to such a degree hat no further exhaustion can be effected.

We have here described the action of the piston in the cylinder or barrel A B; but it is manifest from the construction of the apparatus, that the action of the piston in the cylinder or barrel C D must be precisely similar; and, since the pistons ascend and descend alternately, it is obvious, that for each descent of either of them, a volume of air is expelled equal to the capacity of each cylinder or barrel of the air-pump, multiplied by the density of the air peculiar to each movement.

When the number of strokes of the piston increases in arithmetical progression, the quantity of air remaining in the receiver and also its density, constitute a series of terms decreasing in geometrical progression; and the ratio of decrease—

Is equal to the capacity of the receiver alone, divided by the capacity of the receiver and pump-barrel together.

The principle here enunciated, is that on which the calculations of the air-pump depend; but in order to establish a formula for indicating the density of the air remaining in the receiver at any instant during the operation, we beg leave to propose the following notation, as employed by Professor Mosely in his Hydrostatics:—

Let M = the content of the entire apparatus, consisting of the receiver, cylinders, and other subsidiary spaces;
N = the content of one of the cylinders, or barrels in which the pistons move;
D = the initial density of the air in the receiver,

or that of the atmosphere in its natural state;

D_n = the density of the air in the receiver after n strokes or descents of the piston;

n = the number of descents of the piston, when the air in the receiver has attained the density D_n.

Then, since *the quantities of matter in all bodies, are in the compound ratio of their magnitudes and densities;* it follows, that $D_n \cdot M$ is the quantity of air remaining in the apparatus after the nth stroke or descent of the piston, and the quantity $D_n \cdot N$ of it is expelled by the next descent, or the $(n+1)$th stroke; so that $D_n \cdot M - D_n \cdot N$, is the quantity of air remaining after the piston has descended $(n+1)$ times, and this, by the above mentioned property of bodies, must be equivalent to $D_{n+1} . M$; hence by comparison, we obtain

$$D_{n+1} \cdot M = D_n \cdot M - D_n \cdot N;$$

collecting the terms and dividing both sides of the equation by M, we get

$$D_{n+1} = D_n \left(\frac{M - N}{M}\right);$$

and this, by the law of progression, becomes

$$D_n = D \left(\frac{M - N}{M}\right)^n. \quad . \quad . \quad . \quad (A)$$

Since the symbol D, according to our notation, represents the initial density of the air in the receiver, or that of the atmosphere in its natural state at the surface of the earth, it will be convenient to consider its numerical value as equivalent to unity, in which case the above equation will become transformed into that which follows, viz.:—

$$D_n = \left(\frac{M - N}{M}\right)^n. \quad . \quad . \quad . \quad . \quad (B)$$

By this equation every particular regarding the air-pump can be calculated; from it we learn, that in the same apparatus, there are only two distinct problems that require solution, and these are the following:—

1. *When the number of strokes, or the number of descents of the piston is given, to determine the density.*

2. *When the density is given, to determine the number of strokes or descents of the piston.*

Now the first of these problems receives its solution immediately from the form of the equation, where the value of the density is expressed in terms of the dimensions of the apparatus, and the number of strokes or descents of the piston. It is evident that the numerator of the fraction $\frac{M - N}{M}$, is equal to the difference between the whole capacity of the apparatus, and the capacity of one of the pump-barrels, while the denominator is equal to the entire capacity of the spaces containing air, whether in the barrels or the receiver, and other subsidiary spaces. The fraction thus constituted is therefore the same as the ratio of rarefaction of the air in the receiver, and this circumstance leads us to the following practical rule for calculating the density of the air remaining in the receiver after any proposed number of strokes, or descents of the piston.

RULE.—*Raise the ratio of rarefaction to such a power as is denoted by the number of strokes, and the result will be the density of the remaining air, expressed in parts of the unit or initial density.*

Example 1.—Let it be supposed that the capacity of the receiver, or vessel from which the air is to be extracted, together with the pump-barrels, valve spaces, &c., is equal to 1,200 cubic feet, while the capacity of the pump-barrel or cylinder is 20 cubic feet; what will be the density of the air left in the receiver, after the piston has made 32 strokes or descents?

In this example, the ratio of M to N is as 1,200 to 20, or as 60 to 1; consequently we have $\frac{M - N}{M} = \frac{60 - 1}{60} = \frac{59}{66}$, which is the ratio of rarefaction, or it is the proportional quantity of air remaining in the apparatus after the first descent of the piston, on the supposition that the whole quantity before the descent was represented by unity. Now, if the fraction $\frac{59}{60}$ be raised to the 32nd power, the density, or quantity remaining after 32 descents, will be expressed by the result.

It would, however, be a very tedious operation to raise the fraction $\frac{59}{60}$ to such a high power by the common process of involution; and in order, therefore, to abbreviate the labour and facilitate the operation, we must have recourse to logarithms, for in this way we have only to

Subtract the logarithm of the denominator from that of the numerator, and multiply the remainder by 32, *and the product will be the logarithm of the density required.* The opertion is as follows:—

Given numerator, 59 .	log. 1·7708520	
Given denominator, 60	log. 1·7781513,	subtract.
	log. 9·9927007,	remainder.
	32	
Natural number, 0.584 the density sought, .	log. 9·7664184,	product.

Here, then, the density is 0·584 of the initial density, so that after 32 strokes or descents of the piston, the apparatus is not half exhausted, the vacuum being only 0·416 of the whole vacuum, or entire exhaustion.

Seeing, therefore, that the determination of the density by the common process of involution, for any number of strokes above the third or fourth, is excessively tedious, and that the labour is much shortened by the use of logarithms, it will be convenient to modify the general equation (A), so as to suit the direct application of those numbers. The equation thus modified is as follows:—

$$\log . D_n = \log . D + n \times \left\{\log . (M - N) - \log . M\right\} . \quad (C)$$

This equation is applicable when the initial density D, is of any proposed value ; but when its value is expressed by unity, as in the case of atmospheric density, the equation becomes,

$$\log . D_n = n \times \left\{\log . (M - N) - \log . M\right\} . \ . \quad . \quad (D)$$

This last form of the equation indicates the process which we have performed above, for finding the density of the remaining air after 32 strokes of the piston, on the supposition that the initial density is unity; but when the initial density is of some other value, its logarithm must also be added, as indicated by the equation (C).

Thus, for instance, suppose that the density of the air in the apparatus at the commencement of the operation is only 0·75 of atmospheric density ; then the whole operation for the preceding example, will stand as below.

Given numerator, 59 .	log. 1·7708520
Given denominator, 60	log. 1·7781513, subtract.
	log. 9·9927007, remainder.
	32
	log. 9·7664184, product.
Initial density, 0·75 .	log. 9·8750613, add.
Natural number, 0·438, the density after 32 descents	log. 9·6414797, sum.

Now this operation is sufficiently easy when a table of logarithms is at hand, and it involves the greatest amount of labour that can ever be required in the solution of this particular case, if we except the labour of multiplication when the exponent consists of more than two places of figures, a condition that may very frequently happen when numerous calculations of the same problem are required, such as may be supposed to occur in the arrangement of an extensive set of experiments. A few examples are here annexed for the reader's exercise, as it is by example only that he will become familiar with the mode of performing the operation.

Example 2.—Determine the density of the air after 15.5 strokes, the initial density being 0·63, and the whole capacity of the apparatus to the capacity of the pump-barrel, as 59 to 4. Ans.

Example 3.—What will be the density of the air in the receiver of an air-pump, after 325 descents of the piston, the entire capacity of the apparatus, being to the capacity of the pump-barrel, as 1896 to 12, the air at first being of atmospheric density? Ans.

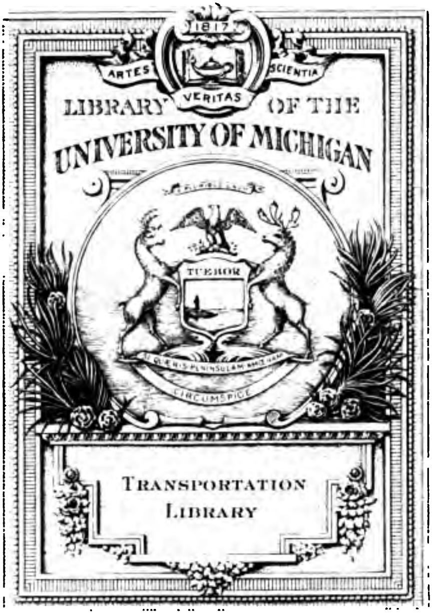
Example 4.—How much will the density of the air in the receiver be reduced by 2½ strokes or descents of the piston, the initial density of the air being 0·625, and the whole contents of the apparatus to the contents of the pump-barrel as 5 to 3? Ans.

In these examples, the density or state of the air in the receiver is required to be expressed in parts of the unit or atmospheric density; this is not, however, the only way in which we express the state or condition of the air during the process of exhaustion; for since the vessel to be exhausted, or the air-pump with which it is connected, is generally furnished with a barometer gauge, for the purpose of indicating the density during the progress of exhaustion, it follows that these indications must be reckoned in inches of the mercurial column, the gauge being so constructed, that 30 in. answer to the complete exhaustion or perfect vacuum. This, therefore, is the most convenient way of expressing the state of the air in the receiver at any specified stage of the operation; but it must be understood, that the number of inches exhibited by the gauge, indicates the state of the vacuum, and the complement of such indication to 30 in. shows the state of the air still remaining in the receiver at the time when the observation is made.

In order to combine the principle which we have been illustrating, with observations on the mercurial gauge, it becomes necessary to propose another set of symbols, to compare with those by which we have expressed the density in parts of the unit. And for this purpose,

Let h = the height of a column of mercury, which, in consequence of its weight, counterbalances the pressure of the atmosphere, and indicates a complete vacuum in the receiver;

h' = the height of mercury in the gauge at the time of observation, indicating the state of the vacuum at that time;



LIBRARY OF THE
UNIVERSITY OF MICHIGAN

TRANSPORTATION
LIBRARY

Transportation
Library
TF
692
T94

the density with this height of gauge, is little more than one-fourth of atmospheric density, when this is indicated by 28·57 inches of mercury.

This case also is too simple to require further illustration by way of example, what has here been done being quite sufficient for elucidating such an easy and obvious process.

When the vessel or receiver has been completely exhausted, and the air re-admitted from the atmosphere, it is obvious that the air within the vessel will become denser and denser as the influx continues, and an equilibrium will obtain when the interior and exterior air are of the same density.

It is also obvious, that the velocity with which the air re-enters the vessel, will vary from the commencement of the influx, becoming continually less and less as the density becomes greater, until the equilibrium is restored between the internal and the external air, when motion will entirely cease. Now, since the greatest velocity takes place at the instant the influx commences, it becomes a matter of importance in this and similar inquiries, to ascertain what that velocity is, as it is made an element for determining the corresponding velocity, at the moment the influent air has attained any particular degree of density, a condition which is constantly indicated by the height of mercury in the barometer gauge.

The writers on pneumatics have demonstrated, that the velocity with which the air of the atmosphere would flow into a perfect vacuum, if free and wholly unobstructed, is the same as that which would be acquired by gravity in a heavy body falling from the height of a column of air of uniform density, capable of producing a pressure on the earth's surface, equal to that produced by the atmosphere in its natural state; we therefore proceed to show in what manner the height of this uniform column is found.

Now, the specific gravity of common mercury, is to that of distilled water as 13.6 to one; consequently, a column of 30 in. of mercury standing on a base of one square inch, is equal to a column of 408 in. of water standing on an equal base; but a column of mercury varying from 28 in. to 31 in. in height, is found to balance the pressure of the atmosphere in all its changes of density, and the heights of the columns of water and mercury of the same weight, are reciprocally as their specific gravities; hence we have for the above-mentioned range,

The column of water.
1 : 13·6 :: 28 : 380·8 inches.
1 : 13·6 :: 29 : 394·4 inches.
1 : 13·6 :: 30 : 408·0 inches.
1 : 13·6 :: 31 : 421·6 inches.

Therefore, since a cubic foot of water, whose specific gravity is represented by unity, weighs exactly 62·5 lbs. avoirdupois; and since each of the columns balances the pressure of the atmosphere, according to its density, we can easily ascertain the pressure of the atmosphere o base of one inch square at the surface of the earth, cording to the above four states of density, as follo viz. :—

Inches.		lbs.		Inches.		per sq. in. of base.
1728	:	62·5	::	380·8	:	13·773 lbs.
1728	:	62·5	::	394·4	:	14·265 lbs.
1728	:	62·5	::	408·0	:	14·757 lbs.
1728	:	62·5	::	421·6	:	15·249 lbs.

Now, the mean specific gravity of the air at the s face of the earth, as compared with that of water 1000, is 1 $\frac{2}{9} = \frac{11}{9}$, and the heights of a column of wa and another of air to produce the same pressure, are versely as the specific gravities; hence we have, for several pressures just calculated, the correspondi heights, as follows :—

	lbs.		oz.*		oz.		Inches.		Uniform height of col. c
For	13·773,	it is	$\frac{132}{9}$	:	1000	::	380·8	:	25963·64 feet
	14·265	,,	$\frac{132}{9}$	:	1000	::	394·4	:	26890·91 feet
	14·757	,,	$\frac{132}{9}$	:	1000	::	408·0	:	27818·18 feet
	15·249	,,	$\frac{132}{9}$	:	1000	::	421·6	:	28745·46 feet

The same heights, however, might have been dedu from the mercury itself, without reducing it to the eq valent column of water, and as our object is to wi hold nothing that may be useful to the young engineer, we think proper to show the operation in this way also. It is as under:—

---

* The numerator 132 is produced by the multiplication o and 11, which brings out the result in feet at once.

oz.	oz.	Inches.	Uniform height of col. of air.
$\frac{132}{9}$:	13600 ::	28 :	25963·64 feet.
$\frac{132}{9}$:	13600 ::	29 :	26890·91 feet.
$\frac{132}{9}$:	13600 ::	30 :	27818·18 feet.
$\frac{132}{9}$:	13600 ::	31 :	28745·46 feet.

In practice, either of these results may be adopted according to the state of the atmosphere at the time of observation, which may always be known by reference to the barometer; it will, however, in general, be most convenient to employ that which custom has sanctioned, namely, 30 in. of the mercurial column, which gives a pressure of 14·757 pounds upon a base of one square inch, and a uniform column of 27818·18 ft. in height: but when great accuracy and a wide range are required, we must be more particular as regards the quantities to be adopted.

It will be observed, that the preceding calculations have reference to the integral inches only in the columns of mercury, but as the barometer scale may indicate any intermediate subdivision, as tenths, or hundredths of the inch, a separate, but similar calculation in that case will be necessary, whether it be for the equivalent column of water, the pressure per square inch of base, or and furthermore, by substituting $13{\cdot}6h$, for H, it is

$$P = 0{\cdot}4919h. \quad . \quad . \quad . \quad . \qquad (L)$$

The atmospheric pressure in pounds per square inc may readily be found from either of these three form but the last is the most convenient, and the following the rule for reducing it.

RULE.—*Multiply the height of the mercurial colun in inches, by the constant fraction* 0·4919, *and the produ will be the pressure of the atmosphere in pounds per squa inch.*

Example.—Suppose the height of the mercurial c lumn to be 29·475 in.; what is the corresponding pre sure of the atmosphere in pounds per square inch?

This is an indication of the barometer between 29 i and 30 in., and, by the foregoing rule, the correspond ing pressure in pounds per square inch is

$$0{\cdot}4919 \times 29{\cdot}475 = 14{\cdot}4988 \text{ lbs.}$$

The same thing, however, may be otherwise don very simply, by merely taking the difference betwee the pressures for 29 in. and 30 in., as previously com puted; then multiply this difference by the given deci mal 0·475, and add the product to the pressure at 29 i for the pressure sought, as follows—

Pressure at 30 in. = 14·757 lbs.
Pressure at 29 in. = 14·265
Remainder = 0·492, which, being mul tiplied by 0·475, we get

of the foregoing operations; and first, as regards the height of a column of water, equivalent in weight to a column of mercury which balances the pressure of the atmosphere, this column being represented by the symbol h. Now, since S denotes the specific gravity of water, and s that of mercury, we have—

$$S : s :: h : H;$$

which, being reduced, gives H as under,

$$H = \frac{s\,h}{S} \quad . \quad . \quad . \quad . \quad . \qquad (K)$$

Rule.—*Multiply the specific gravity of mercury by the height of the column in inches, which balances the pressure of the atmosphere, and divide the product by the specific gravity of water, for the height of a similar column of water, also in inches.*

Examples of this rule have already been given in the first class of analogies preceding, the first of which, worked out according to the rule, is as under, viz.:—

$$\frac{13600 \times 28}{1000} = 380{\cdot}8 \text{ in.}$$

The number of cubic inches in one cubic foot is 1728; consequently, for the value of P, we have as follows, viz.:—

$$1728 : w :: H : P;$$

from which, by reduction, we get

$$P = \frac{H\,w}{1728},$$

and, by substituting 62·5 for w, it becomes,

$$P = 0{\cdot}036169\,H;$$

Mechanics' Institute.

The equations (K), (L), and (M), and the rules derived from them, are all too simple in their form and composition to require further illustration in the way of examples; but, however simple they may be in reality, yet they require the reader's most attentive consideration, as they are of the greatest use in prosecuting the present inquiry, and are of very frequent occurrence in pneumatical investigations generally, but more especially in testing and comparing the results of experiments with the deductions from theory.

We have already intimated, that the velocity with which the air of the atmosphere flows into a vacuum, is the same as that acquired by gravity in a heavy body, falling through the height of a column of uniform density, capable of producing the same pressure on a square inch of base at the surface of the earth, as is produced by an equal column of variable density, extending to the summit of the atmosphere. Now, the writers on mechanics have shown, that the velocity which a heavy body acquires by gravity, in falling from a state of quiescence through the height H′, is expressed by the term $\sqrt{64\frac{1}{3} H'}$, the co-efficient $64\frac{1}{3}$ denoting the double power of gravity, or twice the velocity acquired in one second. Therefore, instead of H′ in this expression, let its equivalent in equation (M) be substituted, and the expression for the initial velocity of air into a vacuum becomes

$$V = \sqrt{64\tfrac{1}{3} \times 927{\cdot}27h},$$

nd this, when reduced to its lowest terms, is

$$V = 244{\cdot}2428 \sqrt{h}. \quad . \quad . \quad . \quad \text{(N)}$$

Rule.—*Multiply the square root of the height of the ercurial column expressed in inches, by the constant coficient* 244·2428, *and the product will be the velocity of flux in feet per second.*

Example 1.—Suppose the mercury in the common arometer to stand at the height of 30 in.; with what elocity will the air rush into a vacuum?

By the rule it is, *velocity* $= 244{\cdot}2428 \sqrt{30} =$ 44·2428 × 5·4772 = 1338·697 ft. per second.

This is the velocity of influx, on the supposition that he vacuum is constantly maintained, and that there is o contraction of the stream of air at the aperture, nor ny other kind of resistance tending to diminish the veocity, the motion being supposed to be perfectly free nd unconstrained.

Example 2.—With what velocity, in feet per second, will the air of the atmosphere flow into a continuous vacuum, at the time the barometer indicates 28·674 in.? Ans.

Example 3.—How much air will pass an aperture of 12 in. diameter in one hour, the air flowing freely into a vacuum which is constantly maintained, and the barometer indicating 29·375 in.; and what space would the same quantity of air occupy, if expanded in a close vessel, until the barometer gauge indicated a rise of 22 in.? Ans.

Example 4.—Determine the velocity with which the air of the atmosphere flows into a vacuum, when the barometer stands at 28 in., and when it stands at 31 in., these being the limits of its range; and what is the height of a column of air corresponding to the difference of these velocities? Ans.

What we have done above, in regard to the velocity of influx, supposes a perfect vacuum to be constantly maintained, a condition which does not obtain in the case of filling a vessel with air, for here the velocity continually varies from that which is due to the vacuum, until the flow entirely ceases, when the air within the vessel is of the same density as that without, an equilibrium obtaining at that point.

Now, in order to calculate the velocity of influx, at the instant when the air in the vessel has attained any degree of density between zero and unity, we must have recourse to the following formula, viz.:—

$$v = V \cdot \sqrt{\frac{D - D_n}{D}} \quad . \quad . \quad . \quad . \quad (O)$$

In which equation D denotes the density of atmospheric air equal to unity, and D_n the density of the air in the vessel at any proposed period of the influx, the symbols v and V denoting the corresponding velocities.

Let the value of V, as given in equation (N), be subtituted instead of it in the form given above, and it becomes

$$v = 244{\cdot}2428 \sqrt{h\,(1 - \underset{n}{D})} \quad . \quad . \quad (P)$$

onsequently, to find the velocity of influx for any given alue of the density, we have the following practical ule in words.

Rule.—*Subtract the given density from unity ; multiply the remainder by the number of inches of mercury dicated by the barometer at the time of observation ; then ultiply the square root of the product by the constant co- fficient* 244·2428, *and the product will be the velocity of flux in feet per second, corresponding to the proposed ensity.* Or thus, according to equation (O). *Subtract he given density from unity, and multiply the square root f the remainder by the velocity in feet per second, with hich the air of the atmosphere flows into a vacuum, and he product will be the velocity sought.*

Example 1.—With what velocity will air of atmos- heric density flow into a vessel containing air of a den- ity equal to ·625, or five-eighths of the unit, the baro- neter standing at 29½ in. ?

By the method described in the first part of the rule ve have 1 — 0·625 = 0·375, and this being multiplied y 29½, gives 0·375 × 29½ = 11·0625, from which we et

$$v = 244{\cdot}2428 \sqrt{11{\cdot}0625} = 812{\cdot}359 \text{ ft. per second.}$$

Example 2.—When the common barometer indicates a height of of 30 in., and the barometer gauge a height of 18 in.; with what velocity will the air of the atmosphere flow into the vessel containing the rarer air? Ans.

Example 3.—When the contained air in a close vessel indicates a density of 0·498 parts of the unit, or atmospheric density; what will be the velocity of influx at the time of observation, the barometer standing at the height of 31 in., and what will be the velocity supposing the barometer to be at 28 in., these being its maximum and minimum limits? Ans.

Example 4.—What is the difference between the velocities with which the air of the atmosphere will flow into a close vessel, containing air of a density equal to 0·875 parts of the unit, and another vessel containing air of a density equal to 0·25 of the unit, the barometer showing a height of 30·75 in. at the time of observation? Ans.

If the several topics which we have now discussed be well understood, the various particulars respecting the density and rarefaction of the air may thereby be calculated, we therefore proceed to consider the other case of the problem in reference to the air-pump; namely, that in which the density of the air is given:—*To determine the number of strokes or descents of the piston requisite to produce that density.*

By recurring to the equation marked (D), in which the value of the density is expressed logarithmically, it will readily be perceived, that in order to resolve the equation in reference to the number of strokes, we have only to divide both sides of the equation by the term [log. (M — N) — log. M], with which the symbol n is combined by multiplication, and we get

$$n = \frac{\log.\ D}{[\log.\ (M - N) - \log.\ M]} \quad . \quad . \quad (Q)$$

Rule.—*Take the difference between the whole capacity or cubic contents of the apparatus, and that of the pump barrel; then, from the logarithm of the remainder, subract the logarithm of the whole capacity, and divide the ogarithm of the given density by the difference; the quotient thus obtained will be the number of strokes required o produce the given density.*

Example.—Supposing the capacity of the whole space containing air in the apparatus to be to the capacity of the pump barrel as 60 to 1; how many strokes of the piston will be required to reduce the air to a density of 0·5275?

In applying the above rule, the reader must be very cautious in the operation as regards the effect of the negative indices, it would in fact be better to avoid them altogether, than to run the risk of the uncertainty as to the result that may arise from their use, and this may be done by simply taking the reciprocal of the terms in the equation; that is, by dividing unity by each of them, the above equation will then assume the following form, viz. :—

$$n = \frac{\log.\ 1 - \log.\ D_n}{\log.\ M - \log.\ (M - N)} \quad .\quad .\quad .\quad (Q^{a})$$

Here then, we have an equation into which the negative indices do not enter in the division, and consequently, there can be no uncertainty as regards the result. The above example, resolved in this way, will therefore be as follows: that is,

Atmospheric density = 1 log. 0·0000000
Given density = 0·5275 log. 9·7222225, subtract.
log. 0·2777775, remainder.
M = 60 . . . log. 1·7781513
M — N = 59 . . . log. 1·7708520, subtract.
log. 0·0072993, remainder.

Consequently, if the first of these remainders be divided by the second, as indicated by the formula, we get 2777775 ÷ 72993 = 38·027 = n, the number of strokes required.

It will however be most convenient to have the density expressed in terms of the inches of mercury as indicated by the barometer gauge, in combination with the density of the atmosphere, and for this purpose we must revert to equation (I), where the density is expressed by ie term $\frac{h-h'}{h}$, where h denotes the height of the baro- eter gauge corresponding to the perfect vacuum, and the height corresponding to the given density. Let is term, therefore, be substituted instead of the den- ty in equation (Q), and by reciprocating the terms we et

$$n = \frac{\log. h - \log. (h - h')}{\log. M - \log. (M - N)} \quad . \quad . \quad (R)$$

Rule.—*From the height of the barometer gauge hich indicates the perfect vacuum, subtract the given ight, or that at which the mercury stands when the ob- rvation is made; then, subtract the logarithm of the re- ainder from the height which indicates the perfect va- uum, and call the difference* A. *From the whole capacity, solid content of the apparatus, subtract the capacity of e pump barrel; then, from the logarithm of the whole ipacity, subtract the logarithm of the remainder, and call e difference* B. *Divide the quantity* A *by the quantity , and the quotient will be the number of strokes or de- ents of the piston sought.*

Example 1.—The whole capacity of the apparatus eing to the capacity of the pump barrel as 60 to 1; ow many descents of the piston will be required to ise the mercurial gauge to the height of 18 in., when ie common barometer stands at its mean height, or 9½ in.?

Atmospheric pressure, 29·5 in. log. 1·4698220,
Height of mercurial gauge . . . } 18
Difference, 11·5 log. 1·0606975, su
Remainder = log. 0·4091242

Proportional capacity of apparatus } 60 . log. 1·7781513
Ditto, of the pump barrel . . } 1
Difference, 59 log. 1·7708520, su
Remainder = log. 0·0072993.

Let therefore, the first of these remainders vided by the second, and we obtain for the nun descents of the piston, $n = 4091242 \div 72993 =$ strokes or descents; and supposing the pump t 28 strokes in a minute, it will take 2 minutes to r gauge to the required height.

Example 2.—The ratio of the capacities rem how many strokes of the piston will reduce the ai receiver to the density of 0·695, the atmospheri sure at the time being indicated by 30 in. of th mon barometer? Ans.

Example 3.—With the same capacities as how many strokes of the pump piston will rar air in the receiver 15 times, the common bar standing at 28 in.? Ans.

Example 4.—When the common barometer is at 9 in., and the ratio of the capacities as before; how many strokes of the piston will reduce the density of he air in the receiver to 0·579; how many will raise he mercurial gauge to 16 in., and how many will rarefy he air 25 times? Ans.

This is a very useful and interesting case of the general problem, and will find its application when we come to treat of that which constitutes the main object of inquiry; namely, the nature and operation of the Atmospheric Railway, to which our attention will very hortly be directed.

Having thus determined the number of strokes of he air-pump necessary to produce any proposed degree of vacuum, the next subject to which our attention must be directed is to determine the mean pressure per square inch of the air-pump piston when working against any proposed degree of vacuum. Now this, by a very simple fluxional process, is found to be expressed in pounds per square inch by

$$p = 0{\cdot}4919\,(h - h')\ \text{hyp. log.}\ \frac{h}{h-h'}, \quad . \quad \text{(S)}$$

Where p denotes the mean pressure, or resistance, in pounds per square inch, the symbols h and h' denoting as hitherto.

Rule.—*Divide the height in inches of mercury which corresponds to the pressure of the atmosphere at the time of observation, by the difference between that height, and the height corresponding to the proposed degree of vacuum*;

then, multiply the hyperbolic logarithm of the quotient the difference just named, and again by the constant fr tion 0·4919, *and the product will be the mean pressure pounds per square inch on the air-pump piston.*

The same thing, however, may be expressed in ter of the density, by simply substituting for h' its val from equation (H), which gives

$$p = 0\cdot4919\, h\, D_n \text{ hyp. log. } \frac{1}{D_n} \quad . \quad . \quad . \quad (T$$

Now, this form of the expression is even simp than the preceding, and the practical rule for reducing is as follows :—

Rule.—*Multiply the hyperbolic logarithm of the ciprocal of the proposed density, by the proposed densit and again by* 0·4919 *times the inches of mercury whi correspond to the pressure of the atmosphere, or to t perfect vacuum, and the product will be the mean pressu in pounds on a square inch of the air-pump piston.*

It might also be expressed in terms of the relati capacities of the whole apparatus and the air-pu barrel, together with any proposed number of strokes the piston; but as this expression would be of rather complex form, we think proper to omit it; the followi very simple form gives the pressure on the air-pu piston in terms of the rarefaction, or the number times that the air is rarefied at any proposed instan that is

$$p = \frac{0\cdot4919h}{r} \text{ hyp. log. } r. \quad . \quad . \quad (U)$$

Rule.—*Multiply the hyperbolic logarithm of the umber of times that the air is rarefied by the inches of ercury which represent the pressure of the atmosphere, nd again by the decimal fraction* 0·4919 ; *then, divide he product by the number of times that the air is rare-ied, for the mean pressure in pounds upon a square inch f the air-pump piston.*

Now, either of these formulæ and rules may be ap-lied according to the conditions of the question, for, ince they are convertible into each other, the same re-ult will be obtained whichever of them is used, provided he data are properly reduced, according to the names of he quantities which constitute the respective formulæ.

Example 1.—What is the mean pressure in pounds er square inch of the air-pump piston corresponding to rise of 18 in. in the vacuum gauge, the pressure of the tmosphere being indicated by 30 in. in the common ba-ometer?

This example requires to be resolved by the rule to quation (S), where we have $\frac{h}{h - h'} = \frac{30}{30 - 18}$; and he hyperbolic logarithm of $\frac{30}{30 - 18} = 2{\cdot}5$, is 0·9162907; herefore, multiplying this by $h - h'$, or $30 - 18 = 12$, e get $0{\cdot}9162907 \times 12 = 10{\cdot}9954884$, and finally, ultiplying this again by 0·4919, it is $10{\cdot}9954884 \times {\cdot}4919 = 5{\cdot}4086$ pounds per square inch.

If we wish to resolve the same example by the rule o equation (T), we have only to find, from equation (I), the density corresponding to 18 in. of vacuum, and then procèed as directed by the rule. Or, if we wish to resolve it by the rule to equation (U), we must find, by equation (E), how often the air is rarefied when the vacuum is indicated by 18 in. of mercury, and then proceed as directed; in either case the result will be the same, and the difference in the quantity of labour will be very small indeed.

Example 2.—When the pressure of the atmosphere counterbalances 30·95 in. of mercury in the tube of the common barometer, what will be the mean pressure in pounds per square inch on the air-pump piston when the vacuum gauge shows a rise of 12 in.? Ans.

Example 3.—When the density of the air in the receiver is 0·825 of atmospheric density; what is the mean pressure per inch of the air-pump piston, the common barometer showing a rise of 29·75 in.? Ans.

Example 4.—When the common barometer is at 28·935 in.; what is the mean pressure on the air-pump piston when the air in the receiver is rarefied $6\frac{1}{2}$ times? Ans.

If we attentively examine the mean pressure as represented by the equation (S), it will be perceived that it admits of a maximum value, and that takes place when the expression $\frac{h}{h-h'}$, is equal to 2·7182818, or when the air is rarefied 2·7182818 times, in which case the hyperbolic logarithm of $\frac{h}{h-h'}$, is equal to unity, and

$h - h' = \frac{h}{2{\cdot}7182818}$, which, being substituted for its equivalent in equation (S), the maximum mean pressure on a square inch of the air-pump piston becomes,

$$p = 0{\cdot}180959h. \quad . \quad . \quad . \quad . \quad \text{(V)}$$

So that if h be equal to 28 in., which is the lowest limit of atmospheric pressure, the maximum mean pressure on a square inch of the air-pump piston will be $0{\cdot}180959 \times 28 = 5{\cdot}066852$ pounds. But when h is equal to 31 in., which is the highest limit of atmospheric pressure, then the maximum mean pressure on the air-pump piston is $0{\cdot}180959 \times 31 = 5{\cdot}609729$ pounds per square inch.

The state of the vacuum corresponding to the maximum mean pressure per square inch of the air-pump piston is as represented by the following equation, viz.;

$$h' = \frac{h\,(2{\cdot}7182818 - 1)}{2{\cdot}7182818} = 0{\cdot}63212\,h. \quad . \quad \text{(W)}$$

Now, when h is equal to 28 in., which indicates the lowest limit of atmospheric pressure, the height of the vacuum gauge corresponding to the maximum mean pressure will be $0{\cdot}63212 \times 28 = 17.69935$ in. But when h is equal to 31 in., which is the highest limit of atmospheric pressure, the height of the vacuum gauge will be $0{\cdot}63212 \times 31 = 19{\cdot}59572$ in.; and at 30 in. of atmospheric pressure the height of the vacuum gauge is $0{\cdot}63212 \times 30 = 18{\cdot}9636$ in.

The foregoing are the principal topics that require consideration in regard to the action of the air-pu and the state or quality of the air in the receiver at proposed instant of operation. Several of the form will be found of the greatest utility in various inqui respecting atmospheric pressure and the exhaustio vessels, and in order to afford the reader the utm possible facility of reference, we think proper to coll the whole into one place, as below:—

1. To determine the density after any number of stroke the piston,

$$D_n = D\left\{\frac{M-N}{M}\right\}^n. \quad \ldots\ldots\ldots \quad ($$

2. To determine the same in the particular case, when atmospheric density is 1,

$$D_n = \left\{\frac{M-N}{M}\right\}^n. \quad \ldots\ldots\ldots \quad ($$

3. Equation (A) expressed logarithmically,

$$\log. D_n = \log. D + n \times \left\{\log.(M-N) - \log. M\right\}. \quad . \quad ($$

4. Equation (B) expressed logarithmically,

$$\log. D_n = n \times \left\{\log.(M-N) - \log. M\right\}. \quad \ldots \quad ($$

5. To determine the number of times that the air is rarefie

$$r = \frac{h}{h-h'}. \quad \ldots\ldots\ldots \quad ($$

6. To determine the height of gauge, for any rarefaction,

$$h' = \frac{h(r-1)}{r}. \quad \ldots\ldots\ldots \quad ($$

7. To determine the height of gauge for any given num of descents,

$$h' = h\left\{1 - \left(\frac{M-N}{M}\right)^n\right\}. \quad \ldots\ldots \quad ($$

8. To determine the height of gauge for any given density,

$$h' = h\left(1 - D_n\right). \quad \ldots\ldots \quad \text{(H)}$$

9. To determine the density for any height of gauge,

$$D_n = \frac{h - h'}{h}. \quad \ldots\ldots \quad \text{(I)}$$

10. To determine the height in inches of a column of water equal in weight to the atmosphere,

$$H = \frac{s\,h}{S}. \quad \ldots\ldots \quad \text{(K)}$$

11. To determine the pressure of the atmosphere on a square inch,

$$P = 0{\cdot}4919\,h. \quad \ldots\ldots \quad \text{(L)}$$

12. To determine the height of an uniform atmosphere in feet,

$$H' = 927{\cdot}27\,h. \quad \ldots\ldots \quad \text{(M)}$$

13. To determine the velocity into a vacuum in feet per second,

$$V = 244{\cdot}2428\sqrt{h}. \quad \ldots\ldots \quad \text{(N)}$$

14. To determine the velocity into rarer air,

$$v = V\sqrt{\frac{D - D_n}{D}}. \quad \ldots\ldots \quad \text{(O)}$$

15. To determine the same when D = 1,

$$v = 244{\cdot}2428\sqrt{h\left(1 - D_n\right)} \quad \ldots\ldots \quad \text{(P)}$$

16. To determine the number of descents of the piston for a given density,

$$n = \frac{\log. D_n}{\log.\,(M - N) - \log.\,M}. \quad \ldots \quad \text{(Q)}$$

17. To determine the same by another form,

$$n = \frac{\log.\,1 - \log.\,D_n}{\log.\,M - \log.\,(M - N)}. \quad \ldots \quad \text{(Q}^a\text{)}$$

18. To determine the same in terms of the apparatus and mercurial columns,

$$n = \frac{\log. h - \log. (h - h')}{\log. M - \log. (M - N)}. \quad . \quad . \quad . \quad . \quad (R)$$

19. To determine the mean pressure on the air-pump piston,

$$p = 0{\cdot}4919\ (h - h')\ \text{hyp. log.}\ \frac{h}{h - h'}. \quad . \quad . \quad . \quad (S)$$

20. To determine the same in terms of the density,

$$p = 0{\cdot}4919\, h\, \underset{n}{D}\ \text{hyp. log.}\ \frac{1}{\underset{n}{D}}. \quad . \quad . \quad . \quad . \quad (T)$$

21. To determine the same in terms of the rarefaction,

$$p = \frac{0{\cdot}4919\, h}{r} \times \text{hyp. log.}\ r. \quad . \quad . \quad . \quad . \quad (U)$$

22. To determine the maximum mean pressure on the air-pump piston,

$$p = 0{\cdot}180959\, h. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (V)$$

23. To determine the state of the vacuum corresponding to the maximum mean pressure,

$$h' = 0{\cdot}63212\, h. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (W)$$

For a complete explanation and illustration of these formulæ, together with the rules for reducing them, reference must be made to their respective letters of signature in the preceding pages of the work. With this notice we dismiss the theoretical part of our inquiry, and proceed to show in what manner the rules which we have laid down are to be rendered available in researches relative to

"THE ATMOSPHERIC RAILWAY."

Mr. James Pim, Jun., treasurer to the Dublin and Kingstown Railway Company, in a letter to the Earl of Ripon, observes, that it is very generally known, that everal ingenious persons have, from time to time, proposed to employ the pressure of the atmosphere as an lement of locomotive power; but their suggestions were so far removed from practical efficiency, that any proposals to adopt an atmospheric, or pneumatic railway, have hitherto been regarded as visionary, and received with contempt and ridicule; indeed, so great has been he prejudice against the principle, that very few, even mong those most interested in railways, have taken he pains to inquire into the matter, or even to inspect what has been done by Messrs. Clegg and Samuda, whose invention has, for some time past, been publicly xhibited on the West London Railway, at Wormwood Scrubs.

It is no longer a question, however, whether trains f carriages can be worked by means of atmospheric ressure, for the experiments made with the apparatus bove mentioned, have proved the practicability of giving motion to considerable loads at a maximum velocity of forty miles an hour; and the greater speed with greater loads that has been attained on other lines since constructed, has completely set the matter at rest as a practical mechanical problem.

The apparatus for producing locomotion on this principle consists of a combination of tubes, valves, air-pumps, and steam engines, and the manner of its arrangement is as follows:—

The moving power is communicated to the trains by means of a continuous pipe, or main of suitable diameter for the power required; this pipe is laid down in the middle of the track, and is supported by the same cross-sleepers to which the chairs and rails are attached. The internal surface of the pipe, or main, being properly prepared by a coating of tallow, a travelling piston, made air-tight by leather packing, is introduced and connected to the leading carriage of each train, by means of an iron plate, or bar, denominated a *coulter*.

In this state of things, if part of the air be withdrawn from that length of the pipe in front of the piston by the air-pump, worked from a stationary steam engine, or by other mechanical means, situated at a suitable distance, a certain amount of pressure on the back of the piston will take place, proportioned to the power employed, or the amount of vacuum produced before the piston.

To work economically in practice, it will be sufficient to produce a degree of exhaustion of air in the pipe, equivalent to causing a pressure from the atmosphere behind the travelling piston of about eight pounds per square inch, which is little more than one half the pressure due to the perfect vacuum, or that which the atmosphere in its natural state exerts upon a square inch of surface.

The iron plate, or coulter, already mentioned, being attached to the travelling piston within the pipe, or main, and also to the leading carriage of the train, it connects them firmly together, moving through a rectangular aperture, or slot, formed on the top of the pipe along the whole of its length. On one side of this rectangular aperture, or slot, is attached, after the manner of a hinge, a continuous flexible valve, or flap, of peculiar construction, closely covering the aperture, and effectually preventing the ingress of air from the atmosphere.

Connected with the piston rod, or coulter, and at some little distance behind the piston, are placed a set of vertical rollers, which progressively lift up a portion of the continuous valve, or flap, while a similar set attached to the carriage close it down again; and it is the very simple, ingenious, and efficient mode of successively opening, closing down, and hermetically sealing this valve as the train proceeds, that constitutes the chief feature and merit of the invention.

From this description of the arrangement, it will be seen that the operation consists, first, in opening a portion of the continuous flexible valve, for admitting the free ingress of the air from without, to press upon the back of the piston, and thus, by its pressure working against a partial vacuum in front, to produce motion; and then, in again effectually closing down and sealing the valve, so as to leave the pipe in a fit state to be exhausted of its air, and to receive, in like manner, the travelling piston of the succeeding train.

It therefore appears, from theoretical considerations, that if the apparatus could be so perfectly constructed, that no leakage of air from without could take place in the vacuum tube during the operation, and that the air-pump could withdraw from the main its full content of air at every stroke of the piston, according to the degree of rarefaction, the only limit to the power of propulsion would be the pressure of the atmosphere, which, in its natural unassisted state, can never exceed fifteen and a quarter pounds upon a square inch of surface; and, moreover, in that case, the maximum velocity of the train would be strictly determined by the proportion existing between the sectional areas of the air-pump and vacuum tube, and the inverse ratio of the velocities of the air-pump piston and the piston in the main. This is obvious, for supposing, in the first place, that no train is attached to the piston, and that it moves freely in the tube without friction or any other kind of resistance; then it is clear, that the tube piston will be advanced during one stroke of the pump, through a space which equal to the content of the air-pump, and every suceding stroke of the pump will produce an equal adnce in the tube.

We have here supposed that no train is attached to e piston, and that it moves in obedience to the superior essure of the atmosphere behind, above that of the rtially rarefied air in front, free from friction or any her kind of resistance whatever. Let us now suppose at a train of some known weight is attached to the ston, it is obvious that this train will offer a resistance the motion proportioned to its weight and its friction the rails; there will, therefore, be no onward motion the train until the air in front of the piston be sufficiently rarefied to cause an excess of pressure of the atosphere on the other side of it, equal to the weight d resistance from friction just mentioned; when this cess of pressure on the opposite sides of the piston as been attained, motion will commence, and the train ill go on accelerating, until the space passed over by e piston in the tube, during a single stroke of the airump, shall be equal to the content of the air-pump; e motion will then continue uniform, and the train ill, in this state, have attained its maximum velocity.

Now, the content of the air-pump in any particular ase is a constant quantity; hence it is manifest, that hether the train moved, be light or heavy, provided hat motion can be impressed upon it by the power ossessed, the maximum velocity attainable will in all cases be the same, the only difference being in the degree of rarefaction required to produce it.

The same limit is therefore put to the maximum velocity of the train, whatever may be the degree of rarefaction in front of the piston; for whatever may be the density of the air that is being withdrawn from the tube, the air-pump can only extract the same number of cubic feet at each stroke, and for this reason, the proportion between the velocities of the two pistons will be constantly the same, when the motion of the train becomes uniform.

Put $D =$ the diameter of the air-pump barrel, estimated in inches;

$d =$ the diameter of the main or vacuum tube, estimated also in inches;

$V =$ the velocity of the air-pump piston, estimated in feet per minute,

$v =$ the velocity of the tube piston, estimated also in feet per minute.

Then, since in the case of a uniform motion, the spaces described by the pistons of the tube and air-pump will always be equal in equal times, the equation by which this condition is expressed becomes

$$D^2 V = d^2 v. \quad . \quad . \quad . \quad . \quad . \quad (X)$$

Such, therefore, would be the simple theory of the atmospheric system of propulsion on railways, provided the apparatus therein employed could be made perfect in every respect, and the air-pump capable of extracting its full content at every stroke. It is well known, however, that this degree of perfection is not attainable in practice; for besides the unavoidable imperfections in working the air-pump, a very considerable leakage of air from the atmosphere takes place at the continuous valve, or flap, which closes the aperture on the top of the pipe, and this leakage is received into the vacuum tube, not at the same degree of density as the atmosphere in its natural state, but dilated according to the degree of rarefaction in the vacuum tube in front of the piston, and for this reason, the effect upon the velocity will vary with different states of the exhaustion.

It therefore appears, that the amount of lost power in consequence of the leakage, and the corresponding diminution of the practical velocity arising from it, constitute the chief, if not the only drawback, on this very ingenious and novel mode of propulsion; and, for this reason, it becomes a matter of the greatest importance that the actual effects of this leakage should be properly understood and duly appreciated.

Now Mr. Robert Stephenson, in his report to the Directors of the Chester and Holyhead Railway Company, on the atmospheric system of transit, remarks, that the most obvious method of determining the amount of leakage is, to observe the rate at which the mercury in the barometer gauge descends from a higher degree of vacuum to a lower; for it is manifest, that the difference between the quantities of air in the tube at the times of observation, will be the amount of leakage that has taken place during the interval.

In order, therefore, to arrive at the knowledge of this very important point, Messrs. Bergin and Stephenson have each performed a set of experiments according to the method above proposed, and which, there is every reason to believe, were performed with as much attention to accuracy as the nature of the subject would admit, although it does appear that in registering the results the same degree of attention has not been observed.

Now, in all cases of this sort, where a great many observations have to be tabulated, these observations, as in the case now under consideration, are usually accompanied with corresponding results obtained by calculation; but these results, in the present instance, are of such a nature, that it does not readily appear in what manner they have been obtained; it consequently happens, that in examining the report, the generality of readers must either admit the results on the responsibility of their authors, or pass them over altogether unnoticed; it is, therefore, as has already been stated in the preface, the chief object of the present undertaking, to put the reader in possession of the rules by which the several particulars can be computed and scrutinized.

The experiments above alluded to were made on the

Kingstown and Dalkey Railway, and those performed and recorded by Mr. Stephenson, are as tabulated below:—

No. of Expt.	Height of Gauge.			Fall.	Interval.	Leakage per minute.
	in.		*in.*	*in.*	*minutes.*	*cubic feet.*
1	21·1	to	7·5	13·6	4	199·770
2	22·4	,,	5·6	16·8	5	197·230
3	21·3	,,	6·3	15·0	12	438·625
4	22·3	,,	5·7	16·6	14	416·067
5	21·0	,,	5·6	15·4	11	355·56
6	21·3	,,	5·5	15·8	11	348·941
7	21·3	,,	6·1	15·2	7	292·925
8	20·9	,,	5·6	15·3	7	294·853

Now, in this table the quantities to be determined by calculation are the leakages, the other tabulated quantities being all supplied by experiment; we are, however, left in the dark as regards the manner in which the calculation is to be performed, as no rule is given for the purpose, nor is any operation exhibited from which the method might be inferred.

It may be true, that the individuals for whom the report was drawn up would not concern themselves about the methods of calculation, the grand objects of their solicitude and scrutiny would be the *pounds, shillings*, and *pence* part of the question, and the probability of obtaining a large return for the capital that they might be induced to invest in the concern.

But with readers in general, and young engineers in particular, the case is very different; to them the principle of the scheme is the main object, and in order that they may be enabled to perform a similar set of experiments, and draw up a similar report, a knowledge of the rules and methods of performing the calculations is indispensable ; and we maintain, that since the report has been printed and sold to the public as an example for the guidance of others in similar undertakings, and that too, under the sanction of a name so eminent, the necessary rules ought to have been given.

It is by taking this view of the subject that we have been induced to investigate a class of formula in reference to the air-pump, and we shall now select from amongst them such as directly apply to the several topics of calculation in the report alluded to.

We have observed, that the quantities in the foregoing table which require calculation are the leakages; now, the formula which is directly applicable to this purpose, is that which is distinguished by the Roman capital (I), a formula that gives the density of the air corresponding to the indications of the vacuum-gauge, from which density the actual quantity of air existing in the tube can easily be ascertained.

If we assume the barometric, or standard indication at 30 in. of the mercurial column, and the density of atmospheric air at unity; then, the density of the air in the apparatus, corresponding to any indication of the vacuum gauge, will be represented in parts of the unit as below, viz. :—

$D_n = \left(\frac{30 - h'}{30}\right)$, and if h'' denote another lower indication, the corresponding density will be

$$D'_n = \left(\frac{30 - h''}{30}\right),$$

Now, each of these results may be reduced to atmospheric density, and the difference between the two will obviously be the quantity of air leaked into the tube, in the time that the vacuum gauge was falling from h' to h''; therefore, by taking the difference of the two densities as expressed above, we get

$$D'_n - D_n = \left(\frac{30 - h''}{30}\right) - \left(\frac{30 - h'}{30}\right) = \left(\frac{h' - h''}{30}\right).$$

Here, then, we have an expression of very great simplicity for determining the thing required, but as we have already remarked, it is not of a nature to be generally known, in consequence of the inquiry to which it is applied not being one of very frequent occurrence, and for this reason only, we presume, has the mode of making the calculations been overlooked; we can assign no other reason, seeing that there is nothing intricate, either in the formula itself, or in the mode of reducing it to practice.

We now proceed to determine the densities of the air corresponding to the several indications in the foregoing table, and from these densities the quantity of leakage in any interval will readily be made known.

Experiment

No. 1. $D'_n - D_n = \frac{21\cdot1-7\cdot5}{30} = 0\cdot453$, density of the leakage.

No. 2. $D'_n - D_n = \frac{22\cdot4-5\cdot6}{30} = 0\cdot560$, ,, ,,

No. 3. $D'_n - D_n = \frac{21\cdot3-6\cdot3}{30} = 0\cdot500$, ,, ,,

No. 4. $D'_n - D_n = \frac{22\cdot3-5\cdot7}{30} = 0\cdot553$, ,, ,,

No. 5. $D'_n - D_n = \frac{21\cdot7-5\cdot6}{30} = 0\cdot536$, ,, ,,

No. 6. $D'_n - D_n = \frac{21\cdot3-5\cdot5}{30} = 0\cdot526$, ,, ,,

No. 7. $D'_n - D_n = \frac{21\cdot3-6\cdot1}{30} = 0\cdot506$, ,, ,,

No. 8. $D'_n - D_n = \frac{20\cdot9-5\cdot6}{30} = 0\cdot510$, ,, ,,

It will be observed, that the leakages here obtained are not the same, nor yet in the same name as those tabulated by Mr. Stephenson, his being expressed in cubic feet per minute of air of the same density as the atmosphere, while ours is the density of the inducted air in parts of the unit, as diffused throughout the whole space during the interval, or the time occupied by the mercury in descending from h' to h''.

In order, therefore, to assimilate the results, it becomes necessary to know the capacity of the space into which the air has leaked, and for this purpose,

Put d = the diameter of the pipe in inches, where the exhaustion takes place ;

ut $f =$ the length of the pipe in feet;
$l =$ the leakage in cubic feet per minute;
$m =$ the interval in minutes between the observations;
$\pi = 3{\cdot}1416$, the circumference of a circle whose diameter is unity;
nd $c =$ the capacity of the tube in cubic feet.

Then, by the rules of mensuration, the quantity of pace in the tube; that is, the capacity expressed in ubic feet is represented by the term $\frac{\pi d^2 f}{576}$, or in form f an equation, it is $c = \frac{\pi d^2 f}{576}$. Therefore, because the uantities of air of different densities contained in any pace, are directly as the densities, and since the density f atmospheric air is denoted by unity, we have

$$1 : \frac{\pi d^2 f}{576} : : \left(\frac{h'-h''}{30\, m}\right) : l = \frac{\pi d^2 f(h'-h'')}{17280\, m}. \quad \text{(Y)}$$

Now, according to Mr. Stephenson's report, the first wo experiments were performed upon the connecting ipe of the Kingstown and Dalkey Railway, the length f the pipe being 1435 ft., and its diameter 15 in.; the apacity in cubic feet is therefore,

$$c = \frac{\pi d^2 f}{576} = \frac{7854 \times 15^2 \times 1435}{144} = 1761 \text{ cubic feet.}$$

Consequently, if each of the first two of the fore-oing densities be multiplied by 1761, we will have the uantity of air of atmospheric density which leaked into he pipe during the interval, and if this quantity be divided by the number of minutes between the indications, the quotient will be the quantity per minute.

Thus, for the leakage per minute in the connecting pipe the expression is $l = \frac{1761\ (h'-h'')}{30}$; but since the part $\left(\frac{h'-h''}{30}\right)$ has already been computed, it need not be again repeated. The leakage per minute in the connecting pipe is therefore as follows :—

Experiment No. 1. $l = 1761 \times 0{\cdot}453 \div 4 = 199{\cdot}58$ cubic feet per minute.

Experiment No. 2. $l = 1761 \times 0{\cdot}560 \div 5 = 197{\cdot}23$ cubic feet per minute.

Now, Mr. Stephenson's tabulated numbers are 199 and 198 respectively; but since he calculates for a capacity of 1765 cubic feet, or 4 feet more than the true capacity, the numbers corresponding ought to have been 200·03 and 197·68 cubic feet; the difference, however, is too trifling to be worthy of notice: but there is an error in the tabulated numbers, which, if employed in the calculation, would produce a discrepancy of greater importance, as in the first experiment it would show a leakage of 228·93 cubic feet per minute, instead of 199·58, the real quantity.

This quantity of leakage it will be seen is due to the connecting pipe alone; now, is it not surprising, that so much leakage should take place in a pipe that might be considered as perfectly air-tight;—whence does it arise? is it at the joining of the sections, or does the ir penetrate the metal itself, and make its way inwardy, in the same manner as water and other fluids penerate and ooze through porous substances? If in either f these ways, the results here obtained are by no means ondemnatory of the system, for it is certainly possible n the present improved state of mechanical manipulaion, to make an air-tight joint, and numerous subtances may be employed as a coating to the metal, hich, by filling the pores, would circumvent any leakge in that way.

The experiments 3 and 4, (numbered 5 and 6 in Mr. tephenson's table,) refer to a portion of the valve tube, ombined with the connecting pipe, making together a ength of 8578 ft., or 7143 ft. for the valve tube alone. ow this, for a tube of 15 in. diameter, gives a capacity f 8766 cubic feet, for we have

he capacity $= c = \frac{\pi d^2 f}{576} = \frac{0{\cdot}7854 \times 15^2 \times 7143}{144} = 8766,$ ubic feet very nearly.

Mr. S. makes it 8786 cubic feet, differing by no less han 20 ft. from what it in reality is; this error it may e remarked, is of little consequence in a case of experinental research: but since the success of a very singular nd novel invention was, in a great measure dependant n the results, and being at the mercy of one of its most owerful opponents, at least one who was the most likely o be benefitted by its failure, the actual quantities, and ot the approximative ones, ought in every case to have een employed.

We do not mean by this to insinuate that any unfair advantage was taken in regard to the experiments themselves, but whoever reads the report with attention, cannot fail to observe throughout, a manifest disposition to throw the invention overboard, and to sacrifice its utility in the furtherance of its antagonist system.

The line itself on which the experiments were made was inappropriate for the purpose, but nevertheless, the results there obtained under all the existing disadvantages, were sufficiently satisfactory to prove that the proposal is something more than visionary, and that under certain improved mechanical arrangements, the invention is one of very high promise, and ought to be examined with the strictest impartiality by those whose word and opinion can save or condemn it, whatever may be its intrinsic merits or demerits as a means of locomotion. But to return to the calculation of the leakage for the other experiments.

The formula when adapted to the given capacities of the valve tube and connecting pipe, in the experiments 3 and 4, is $l = \frac{10527\ (h' - h'')}{30\,m}$, of which the part $\left(\frac{h'-h''}{30}\right)$ has already been calculated. We therefore have in experiments 3 and 4 as follows :—

Experiment No. 3. $l = 10527 \times 0{\cdot}5 \div 12 = 438{\cdot}625$ cubic feet per minute.

Experiment No. 4. $l = 10527 \times 0{\cdot}553 \div 14 = 416{\cdot}067$ cubic feet per minute.

Now Mr. Stephenson, in the one case, makes the otal leakage per minute 450 cubic feet, and in the other ase it is 419; but in each case he separates these leakges into 219 cubic feet for the connecting pipe, and 31 and 200 cubic feet respectively for the valve tube.

Experiments 5 and 6 (numbered 11 and 12 in Mr. tephenson's table), were made upon a length of pipe, ncluding the connecting pipe, of 5938 ft., giving for the alve tube a length of 4503 ft.; then, with this length nd a diameter of 15 in., the capacity is

$$c = \frac{\pi d^2 f}{576} = \frac{0{\cdot}7854 \times 15^2 \times 4503}{144} = 5527 \text{ cubic feet.}$$

Mr. Stephenson makes it 5539 cubic feet, a quantity onsiderably above what is sanctioned by the linear limensions.

The capacity of the space receiving the leakage, inluding that of the connecting pipe, is 7288 cubic feet, nd the formula for the leakage per minute in this case, s $l = \frac{7288\,(h'-h'')}{30\,m}$, the value of the part $\left(\frac{h'-h''}{30}\right)$ having lready been calculated. We therefore have, in experiments 5 and 6, as follows:—

Experiment No. 5. $l = 7288 \times {\cdot}536 \div 11 = 355{\cdot}56$ cubic feet per minute.

Experiment No. 6. $l = 7288 \times {\cdot}526 \div 11 = 348{\cdot}941$ cubic feet per minute.

In the report the total leakages are given at 356 cubic feet per minute in each case, separating them into 219 cubic feet for the connecting pipe, and 137 cubic feet for the valve tube; it is however easy to see from the indications of the vacuum gauge, that the leakage in both cases cannot be the same, and hence we conclude that the tabulated numbers are not what they ought to be.

The experiments 7 and 8, (numbered 17 and 18 in the table of experiments,) were made upon a length of 3298 ft., including the connecting pipe, giving for the valve tube a length of 1863 ft., and consequently the capacity is

$$c = \frac{\pi\, d^2 f}{576} = \frac{0{\cdot}7854 \times 15^2 \times 1863}{144} = 2286 \text{ cubic feet.}$$

In the report the capacity in this case is given at 2292 cubic feet; to which add 1761 for the connecting pipe, and the whole capacity which receives the leakage is 4047. Consequently the formula for the leakage in this case, becomes $l = \frac{4047\,(h' - h'')}{30\,m}$; hence, in experiments 7 and 8, it is as follows:—

Experiment No. 7. $l = 4047 \times 0{\cdot}506 \div 7 = 292{\cdot}925$ cubic feet per minute.

Experiment No. 8. $l = 4047 \times 0{\cdot}510 \div 7 = 294{\cdot}853$ cubic feet per minute.

Now, the total tabulated leakages in these two experiments, are 291 and 295 cubic feet respectively, differing but little in this case from our own results; but till allowing a constant influx of 219 cubic feet per ninute for the air-pump and connecting pipe.

In the preceding calculation of the leakage per miute in the connecting pipe alone, and also in the conecting pipe, combined with portions of the valve tube f different lengths, it will be perceived, that in each ase we have calculated for the extreme indications of he vacuum gauge, and divided by the number of minutes hat elapsed during the observation, for the average eakage per minute. Now this method would be perectly just, on the supposition that the quantity of leakge is constant, or of the same amount in equal times; ut the idea of a constant amount of leakage is altogeher incompatible with what we know to take place, hen air of atmospheric density is allowed to flow into vessel containing air of a less density. Here it is obious that the air in the vessel is continually approachng to a state of equilibrium with that without, and conequently the velocity of influx is continually diminishing ntil the equilibrium obtains.

Now, in the case of the connecting pipe and air pump hen the apparatus is quiescent, the apertures through hich the leakage takes place must be invariable under very circumstance; and since the velocity of influx is ontinually varying, it is not easy to conceive how the uantity of leakage can be constant under all pressures. t all events, it is contrary to what would be expected heoretically, and it is very probable that there is some cause for the results of experiment pointing so decidedly to a constant amount.

Let us examine this circumstance a little more minutely, for which purpose we revert to the first and second experiments, as recorded by Mr. Stephenson, where it appears that the indications of the vacuum gauge were taken for every minute; and certainly, from the regularity of the fall, we would be led to infer that the amount of leakage is constant.

The following table contains the quantities as they were observed, and by calculating the density for each minute, we will be enabled to determine the rate of influx for the several rates of rarefaction at the times of observation. In this table the numbers in the upper row are the minutes during which the observations continued, and those in the other rows are the indications of the gauge at each minute for the first and second experiments, expressed in inches of mercury.

No.	min. 0	min. 1	min. 2	min. 3	min. 4	min. 5
1	21·1	17·6	14·3	10·9	7·5	
2	22·4	19·0	15·5	11·9	8·4	5.6

The object of the previous calculation was to determine the quantity of air which made ingress to the pipe during the time of observation; but in the present instance the object is to ascertain the density of the air in the pipe at each minute of the interval, and from thence to determine the velocity of influx. This will enable us to assign the area of the apertures through which the leakage takes place, and may probably suggest some method of obviating the evil.

The formula for the density corresponding to any state of the vacuum gauge, is $\underset{n}{D} = \left(\frac{30-h}{30}\right)$, see equation (I), and the several densities so computed are as follows:—

In experiment No. 1. $\underset{n}{D} = \frac{30-21{\cdot}1}{30} = {\cdot}296$; $\underset{n}{D} = \frac{30-17{\cdot}6}{30} = {\cdot}413$; $\underset{n}{D} = \frac{30-14{\cdot}3}{30} = {\cdot}523$; $\underset{n}{D} = \frac{30-10{\cdot}9}{30} = {\cdot}636$; $\underset{n}{D} = \frac{30-7{\cdot}5}{30} = {\cdot}75$.

In experiment No. 2. $\underset{n}{D} = \frac{30-22{\cdot}4}{30} = {\cdot}253$; $\underset{n}{D} = \frac{30-13}{30} = {\cdot}36$; $\underset{n}{D} = \frac{30-15{\cdot}5}{30} = {\cdot}483$; $\underset{n}{D} = \frac{30-11{\cdot}9}{30} = {\cdot}603$; $\underset{n}{D} = \frac{30-8{\cdot}4}{30} = {\cdot}72$; $\underset{n}{D} = \frac{30-5{\cdot}6}{30} = {\cdot}813$.

Having thus determined the density in parts of the unit for every indication of the vacuum gauge during both experiments, the velocity with which the air of the atmosphere will flow into the pipe at each of those densities can easily be computed; the equation (P) applies to this determination, and if we substitute 30 for h, it becomes—

$$v = 244{\cdot}2428\sqrt{h\left(1-\frac{D}{n}\right)} = 244{\cdot}2428\sqrt{30\left(1-\frac{D}{n}\right)}.$$

Now, in order to apply this formula to the calculation of the velocity, we have only to substitute the computed densities separately, instead of the symbol $\frac{D}{n}$, and then to reduce the expressions according to the rule appropriated to the particular equation. The operation for each case is indicated as below.

In the first experiment, it is

At the beginning of 1st minute— feet per second.

$$v=244{\cdot}2428\sqrt{30\,(1-0{\cdot}296)}=244{\cdot}2428\sqrt{21{\cdot}1}=1121{\cdot}92$$

End of first minute—

$$v=244{\cdot}2428\sqrt{30\,(1-0{\cdot}413)}=244{\cdot}2428\sqrt{17{\cdot}6}=1024{\cdot}65$$

End of second minute —

$$v=244{\cdot}2428\sqrt{30\,(1-0{\cdot}523)}=244{\cdot}2428\sqrt{14{\cdot}3}=923{\cdot}61$$

End of the third minute —

$$v=244{\cdot}2428\sqrt{30\,(1-0{\cdot}636)}=244{\cdot}2428\sqrt{10{\cdot}9}=806{\cdot}37$$

End of fourth minute—

$$v.=244{\cdot}2428\sqrt{30\,(1-0{\cdot}750)}=244{\cdot}2428\sqrt{7{\cdot}5}=668{\cdot}89$$

In the second experiment, it is

At the beginning—

$$v=244{\cdot}2428\sqrt{30\,(1-0{\cdot}253)}=244{\cdot}2428\sqrt{22{\cdot}4}=1155{\cdot}97$$

End of first minute —

$$v=244{\cdot}2428\sqrt{30\,(1-0{\cdot}366)}=244{\cdot}2428\sqrt{19{\cdot}0}=1064{\cdot}63$$

End of second minute —

$$v=244{\cdot}2428\sqrt{30\,(1-0{\cdot}483)}=244{\cdot}2428\sqrt{15{\cdot}5}=961{\cdot}58$$

End of third minute —

$$v=244{\cdot}2428\sqrt{30\,(1-0{\cdot}603)}=244{\cdot}2428\sqrt{11{\cdot}9}=842{\cdot}55$$

nd of fourth minute — feet per second.

$$v=244{\cdot}2428\,\sqrt{30\,(1-0{\cdot}720)}=244{\cdot}2428\,\sqrt{8{\cdot}4}=\ 707{\cdot}88$$

nd of fifth minute —

$$v=244{\cdot}2428\,\sqrt{30\,(1-0{\cdot}813)}=244{\cdot}2428\,\sqrt{5{\cdot}6}=\ 577{\cdot}98$$

Now, these are the velocities with which the air from ithout is entering the pipe at each minute during the xperiment. Considering, therefore, that the apertures y which the air is admitted must, as regards the conecting pipe and air pump, remain constantly of the ame area, it does not appear, by comparing the above esults, that the same quantity of air can enter in the ame time at all pressures; in fact, by making the comarison, we are led to a very different conclusion, and e are somewhat apprehensive that, by assuming a contant amount of leakage for the connecting pipe, some ery erroneous deductions must have been made.

But with regard to the valve tube the case is very ifferent; for it is easy to conceive that, as the longidinal slot or aperture is covered with a flexible subance, this substance will readily accommodate itself to ie pressure as the exhaustion goes on, and by thus diinishing the area of the aperture as the velocity of inux increases, a constant amount of leakage, or nearly , may happen to be maintained: at all events, it is not consistent with the maxims of accurate science, to adit that such may be the case, and it actually appears from experiment that the supposition is not far from tl truth.

We will now direct the reader's attention to the m thod of calculating the area of the openings or apertur through which the leakage takes place, and for that pu pose we again have recourse to the results of the fir and second experiments, as previously registered in small tablet. These experiments have reference to th leakage at the air-pump and connecting pipe, the onl sources where the areas of inlet can be considered con stant.

Now, in the first experiment, it appears that the ba rometer gauge fell from 21·1 in. at the commencemen to 17·6 in. at the end of one minute; consequently, b the formula for the quantity of leakage, we obtain, fc the leakage during the minute, as follows:—

$$l=\frac{1761(h'-h'')}{30}=58{\cdot}7\,(21{\cdot}1-17{\cdot}6)=205{\cdot}45 \text{ cubic f}$$

In the next minute the mercury fell from 17·6 in. t 14·3 in., being a fall of 3·3 in. in one minute; henc by the formula, we have—

$$l=\frac{1761\,(h'-h'')}{30}=58{\cdot}7\,(17{\cdot}6-14{\cdot}3)=193{\cdot}71 \text{ cubic f}$$

In the succeeding, or third minute, the fall was fro 14·3 to 10·9 in., giving a fall of 3·4 in. per minute; th corresponding leakage is therefore as under—

$$l=\frac{1761\,(h'-h'')}{30}=58{\cdot}7\,(14{\cdot}3-10{\cdot}9)=199{\cdot}58 \text{ cubic f}$$

In the fourth and last minute the mercury fell from 10·9 in. to 7·5 in.; thereby giving a fall of 3·4 in., and a leakage of 199·58 cubic feet,—the same as before for the third minute; the computed velocity of influx at the end of the third minute may therefore be taken as the medium velocity during the third and fourth minutes.

Now, by the rules of mensuration, the area of the nlet spaces must be equal to the quantity of leakage divided by the velocity of influx; therefore, multiplying the medium velocity by 60, for the purpose of assimilation, we get 806·37 × 60 = 48382·2 feet per minute. But the quantity of leakage per minute is 199·58 cubic feet; hence, by division, we get for the area of the aperture, as below:—

$$area = \frac{199{\cdot}58}{48382{\cdot}2} = 0{\cdot}004125 \text{ of a foot square,}$$

$$\text{or } 0{\cdot}594 \text{ of a square inch.}$$

The arithmetical mean of the leakages for the first and second minutes of the experiment, is also 199·58 cubic feet, for $\frac{1}{2}$ (205·45 + 193·71) = 199·58; but the velocity which corresponds to the end of the first minute, 1024·65 feet per second, or 61479 feet per minute. This gives an area of 0·003247 of a square foot, being considerably less than in the case for the last two minutes; the mean of these will therefore be very near the truth: that is—

$$\textit{area} = \tfrac{1}{2}(0{\cdot}004125 + 0{\cdot}003247) = 0{\cdot}003686 \text{ of a square foot, or } 0{\cdot}531 \text{ of a square inch.}$$

Pursuing a similar mode of operation with the results of the second experiment, we find the area to be 0·5299 of a square inch; so that we may consider the area of the inlets to be very nearly ascertained, the truth of which may be proved as follows:—We find, by a very simple differential process, that the mean velocity throughout the interval is 902·42 feet per second; and by our formula for the quantity of leakage, that the whole quantity leaked during the experiment is 798·32 cubic feet; for it is $l = \frac{1761\,(21{\cdot}1 - 7{\cdot}5)}{30} = 798{\cdot}32$. Now the time of the experiment was four minutes, and the mean velocity of influx was 902·42 feet per second, or 216580·8 feet in four minutes; therefore, by division we get—

$$\textit{true area} = \frac{798{\cdot}32}{215580{\cdot}8} = 0{\cdot}003686 \text{ of a square foot.}$$

The area of inlet being thus determined, can its situation not be ascertained, and its effects remedied? We think it may; for we can see no reason why such an amount of leakage should be permitted to obtain, in a part of the apparatus where nothing of the kind might be expected, at least nothing like the amount of 219 cubic feet per minute, which in the report is stated to be constant at all pressures.

It is not necessary to pursue the enquiry in reference to the area of inlet in the valve tube, for there can be no doubt it varies with the degree of pressure in the tube, and for this reason the amount of leakage may approach to a constant quantity at all pressures, or nearly so; and it appears, from the experiments that have been made on the Kingstown and Dalkey Railway, that this amount is very considerable.

Admitting, therefore, that the amount of leakage into the valve tube is constant at all pressures, and that the leakage by the air-pump and connecting pipe is inconsiderable, as in the case of superior workmanship and caution it ought to be; we now proceed to enquire what will be the effect of such leakage on the motion of the piston in the valve tube.

The effect of leakage on the motion of the piston in the valve tube is of much more importance than might at first view be imagined, and its effect is magnified in proportion as the rarefaction of the air proceeds. This is obvious, for all the air that enters into the vacuum tube must be dilated according to the degree of rarefaction indicated by the barometer gauge; and for this reason the effect of the leakage on the velocity of the tube piston must vary for different heights of the mercurial column.

Whatever, therefore, may be the quantity of leakage corresponding to any indication or height of the vacuum gauge, calculated after the manner heretofore illustrated, this leakage must be rarefied in the same degree as the previously included air, and consequently, its retarding influence on the velocity of the piston becomes greater and greater, according to the degree of exhaustion.

If, therefore, the quantity of leakage per minute corresponding to any height of the barometer gauge be divided by the density of the air in the tube corresponding to that height,—or, which is the same thing, if the quantity of leakage be multiplied by the number of times that the air is rarefied,—the quotient in the one case, and the product in the other, will indicate the effect of the leakage in retarding the velocity of the piston in the valve tube. Now the formula by which we have represented the density of air, corresponding to any height of gauge is that marked (I), the application of which we have already fully illustrated; and that marked (E) denotes the number of times that the air is rarefied in the tube; but these equations, it will be seen, are simply the reciprocals of one another: hence, if e be put to denote the effects of any quantity of leakage indicated by l, then we have—

$$e = \frac{l\,h}{h - h'} = \frac{30\,l}{30 - h'} \quad . \quad . \quad . \quad . \quad . \quad (Z)$$

This is the number of cubic feet of air to be extracted by the air-pump in consequence of the leakage, not, however, at the density of the atmosphere, but dilated according to the degree of rarefaction as indicated by the mercurial gauge, and expressed in the above equation by the symbol h'.

Now since the motion of the air-pump piston is supposed to be uniform, and the capacity of the pump barrel onstantly the same, whatever may be the degree of arefaction of the air to be withdrawn from the tube, it s obvious that the effect of the leakage will be increased ccordingly, and the velocity of the piston in the valve ube is therefore proportionally decreased.

Reverting again to the first of the foregoing experinents, we find that the mercury fell from 21·1 in. to 7·6 in. in one minute, and from 17·6 in. to 14·3 in. in he next minute; and the mean of the leakages prolucing these falls is 199·58 cubic feet per minute, as ve have already shown by a previous computation: herefore, by the above formula, we obtain—

$$\textit{effect of leakage} = \frac{30 \times 199{\cdot}58}{30 - 17{\cdot}6} = 482{\cdot}855 \text{ cubic feet.}$$

In this case, therefore, the quantity of air to be exracted by the pump in each minute, supposing the auge to remain stationary, will be increased by 482·855 ubic feet above what would have to be extracted if no eakage took place.

Now the air-pump on the Kingstown and Dalkey ailway is 66½ in. in diameter, and 5½ feet stroke; herefore, by the rules of mensuration, the capacity of he pump is—

$$66{\cdot}5^2 \times 0{\cdot}7854 \times 5{\cdot}5 \div 144 = 132{\cdot}658 \text{ cubic ft.}$$

Consequently, if the effect of the leakage be divided by the capacity of the pump, the quotient will be the number of additional strokes per minute that the air-pump must make, to maintain the gauge at the height of 17·6 in.; thus we have—

482·855 ÷ 132·658 = 3·6398 additional strokes.

Such, therefore, is the very simple method of estimating the effect of the leakage corresponding to any indication of the barometer gauge; but there is another method by which this effect may be ascertained, and that is, by observing the number of strokes of the air-pump necessary to maintain any proposed degree of vacuum, and then comparing this observed number with that which theory would require if there were no leakage: the difference between the observed and computed results will obviously be the number of extra strokes required in consequence of the air that has leaked into the tube.

We are not in possession of any experiments that have been made in the manner here mentioned on the Kingstown and Dalkey line; but in a case where the capacities of the air-pump, the connecting pipe, and valve chambers together, were to the capacity of the pump barrel alone in the ratio of 85 to 1, the following set of experiments was performed in the way specified, from which results the effect of leakage can be very easily and correctly estimated, provided the observations are accurately made.

No. of Exp.	Values of h' observed.	No. of strokes observed.	No. of strokes computed.
1	10	38	34·26
2	11	—	38·59
3	12	52	43·16
4	13	—	47·99
5	14	68	53·12
6	15	74	58·57
7	16	88	64·40
8	17	—	70·66
9	18	118	77·42
10	19	138	84·78
11	20	166	92·83
12	21	—	101·73

Now the theorem for computing the number of trokes of the air-pump that would be necessary to proluce the given value of h', on the supposition that there s no leakage, and that the air-pump is perfect in itself, is hat which we have distinguished by the letter (R), and when this theorem is modified for the ratio M : N : : 85 : 1, t becomes,—

$$n = \frac{\log. h \times \log. (h - h')}{\log. M - \log. (M - N)} = \frac{\log. 30 - \log. (30 - h')}{\log. 85 - \log. (85 - 1)}$$

And when the formula thus modified is applied to alculate the values of the symbol n, corresponding to he several observed values of h', we have the following eries of operations, viz. :—

per minute.

$$n = \frac{\log. 30 - \log. (30 - 10)}{\log. 85 - \log 84} = \frac{1760913}{51396} = 34{\cdot}26 \text{ strokes of piston.}$$

$$n = \frac{\log. 30 - \log. (30 - 11)}{\log. 85 - \log. 84} = \frac{1983677}{51396} = 38{\cdot}59 \text{ strokes of piston.}$$

per minute.

$$n=\frac{\log. 30-\log. (30-12)}{\log. 85-\log. 84}=\frac{2218488}{51396}=43{\cdot}16\text{ strokes of piston.}$$

$$n=\frac{\log. 30-\log. (30-13)}{\log. 85-\log. 84}=\frac{2466724}{51396}=47{\cdot}99\text{ strokes of piston.}$$

$$n=\frac{\log. 30-\log. (30-14)}{\log. 85-\log. 84}=\frac{2730013}{51396}=53{\cdot}12\text{ strokes of piston.}$$

$$n=\frac{\log. 30-\log. (30-15)}{\log. 83-\log. 85}=\frac{3010300}{51396}=58{\cdot}57\text{ strokes of piston.}$$

$$n=\frac{\log. 30-\log. (30-16)}{\log. 85-\log. 84}=\frac{3309933}{51396}=64{\cdot}40\text{ strokes of piston.}$$

$$n=\frac{\log. 30-\log. (30-17)}{\log. 85-\log. 84}=\frac{3631779}{51396}=70{\cdot}66\text{ strokes of piston.}$$

$$n=\frac{\log. 30-\log. (30-18)}{\log. 85-\log. 84}=\frac{3979401}{51396}=77{\cdot}42\text{ strokes of piston.}$$

$$n=\frac{\log. 30-\log. (30-19)}{\log. 85-\log. 84}=\frac{4357286}{51396}=84{\cdot}78\text{ strokes of piston.}$$

$$n=\frac{\log. 30-\log. (30-20)}{\log. 85-\log. 84}=\frac{4771213}{51396}=92{\cdot}83\text{ strokes of piston.}$$

$$n=\frac{\log. 30-\log. (30-21)}{\log. 85-\log. 84}=\frac{5228788}{51396}=101{\cdot}73\text{ strokes of piston.}$$

The numbers corresponding to the blank spaces in the foregoing table were not observed, but by comparing the observed with the computed numbers as far as they go, it will be perceived that the higher the degree of vacuum the greater is the difference between the observed and computed number of strokes. Now this difference can arise from nothing but the effects of leakage into the apparatus at the valves of the air-pump, the joints of the longitudinal valve, and the pistons of the valve tube and air-pump.

We have next to enquire what will be the retarding effect of this leakage upon the velocity of the piston in the valve tube; for this, be it understood, is the chief point in which the leakage becomes detrimental to the atmospheric scheme, not only in as far as it augments the requisite power of the engine, but also in diminishing the speed below what is attainable by other means, and thus placing it at a very considerable disadvantage in the comparison.

If we resolve the equation (X) in reference to the symbol v, which indicates the velocity of the tube piston in feet per minute, on the supposition that there is no leakage, and that the velocity has attained a state of uniformity, we get—

$$v = \frac{D^2 V}{d^2} \quad . \; . \; . \; . \; . \; . \; . \; . \quad (A\,A)$$

This equation gives the maximum theoretical velocity of the vacuum tube piston in feet per minute, expressed in terms of the diameters of the tube and the air-pump, together with the velocity of the air-pump piston; but in order to compare it with the velocity in miles per hour, we must multiply by the number of minutes in one hour, and divide by the number of feet in one mile; consequently, if v' be put to denote the maximum theoretical velocity in miles per hour, we have—

$$v' = \frac{60\,D^2 V}{5280\,d^2} = \frac{D^2 V}{88\,d^2} \; . \; . \; . \; . \; . \; . \; . \quad (A\,B)$$

This equation calculates the theoretical maximum velocity in miles per hour, the given velocity of air-pump piston being expressed in feet per minute. The practical rule for its reduction is as follows :—

RULE.—*Multiply the square of the diameter of the air-pump piston in inches by its velocity in feet per minute, and divide the product by* 88 *times the square of the diameter of the tube piston in inches ; the quotient will be the velocity in miles per hour, on the supposition that there is no leakage.*

Example.—The diameter of the air-pump is $66\frac{1}{2}$ in., and that of the valve tube is 15 in. ; what is the maximum uniform velocity of the tube piston in miles per hour, that of the air-pump piston being 253 feet per minute ?

Diameter of the air-pump 66·5 in. ; its square $66{\cdot}5^2 = 4422{\cdot}25$.

Velocity of air-pump piston in feet per minute = 253 ; consequently, by multiplication, we get $4422{\cdot}25 \times 253 = 1118829{\cdot}25$.

Diameter of the valve tube 15 in. ; its square $15^2 = 225$.

Constant number, or co-efficient, 88 ; therefore, by multiplying according to the rule, we get $225 \times 88 = 19800$; then, if the first of these products be divided by the second, the velocity in miles per hour is—

$$velocity = 1118829{\cdot}25 — 19800 = 56{\cdot}506 \text{ miles.}$$

Since our main object is to supply the rules for calculating every particular connected with the air-pump l the atmospheric apparatus, we must, in conformity our plan, adapt the above formula for logarithmic ration, and when so adapted, it is as below, viz.:—

$$. v' = 2. \log. \mathrm{D} + \log. \mathrm{V} - 2. \log. d - \log. 88 \quad . \quad (\mathrm{A\,C})$$

The process indicated by this expression is so very dent, that it scarcely needs description; but the pracıl rule is as underneath:—

RULE.—*To twice the logarithm of the diameter of the -pump piston in inches add the logarithm of its velocity feet per minute; from the sum subtract twice the logahm of the diameter of the valve tube piston, and also the arithm of the constant number* 88*; then the natural nber answering to the remainder will be the velocity in es per hour.*

Working, therefore, with the data of the preceding ımple, we have the following operation, viz.:—

ımeter of the air-pump piston 66·5 in. . . .	2 log.	3·6456432	
ımeter of the valve tube piston 15 in.	2 log.	2·3521826,	subtract.
	log.	1·2934606	add
locity of the air-pump piston 253 ft. per minute	log.	2·4031205	
nstant number, 88	ar. co. log.	8·0555173	
tural number, 56·506 miles per hour . . .	log.	1·7520984,	sum.

It is easy to perceive that a similar operation to the above would be required for an apparatus of any other given dimensions, and the velocity thus computed is the greatest that can be attained, on the supposition that there is no leakage, and that the motion of the air-pump is uniform, removing its full content at every stroke. We have, therefore, now to enquire what will be the actual velocity, or that which will obtain in the apparatus as affected by leakage.

Now we have already seen that the effect of leakage varies with the degree of rarefaction of the air in the vacuum tube, and in order to obtain the velocity as corrected for leakage, we have only to subtract its effects, according to the indication of the barometer gauge, from the constant maximum velocity computed above, and the remainder will be the velocity thus corrected.

Equation (Z) shows the effect of leakage per minute when expanded according to the degree of rarefaction indicated by the barometer gauge; let this number of cubic feet of leakage be reduced to a column of equal diameter with the valve pipe, and the result will show the length of pipe in linear feet, which operates to retard the velocity of the piston, and which the pump must remove each minute, in order to counteract its effects; it is this length of pipe which constitutes the correction for the velocity, for it is very evident that if there had been no leakage the piston would have been so much farther in advance, as computed by the theorem for the maximum uniform velocity.

The effect of leakage per minute corresponding to he degree of rarefaction, is expressed by the term $\frac{l\,h}{h-h'}$, nd when this is reduced to miles per hour as stated bove, it becomes $\frac{576\,lh}{88\,\pi\,d^2\,(h-h')}$, and subtracting this rom the uniform maximum velocity, as exhibited in quation (A B), we obtain—

$$v'' = \frac{1}{88d^2}\left\{D^2V - \frac{576\,l\,h}{\pi\,(h-h')}\right\} \quad . \; . \; . \; . \quad (A\,D)$$

In which equation the symbol π denotes the constant uantity 3·1416, or it is the circumference of a circle aving unity for its diameter, a term which has only een introduced for the purpose of generalization; and n like manner, the symbol v'' denotes the velocity in niles per hour, corrected for the effects of leakage: onsequently, if for h in the preceding equation we substitute 30 in., which is the standard height of the merurial column, the equation for the velocity in miles per our, when corrected for the effects of leakage, becomes

$$v'' = \frac{1}{88d^2}\left\{D^2V - \frac{5500{\cdot}395\,l}{(30-h')}\right\}. \quad . \quad (AE)$$

And if this expression be adapted to the particular ase of the Kingstown and Dalkey Railway, we have

$$v'' = 56{\cdot}506 - \frac{0{\cdot}2778\,l}{30-h'}. \quad . \; . \; . \; . \quad (AF)$$

In which equation l denotes the leakage in cubic feet er minute, which must be determined by some of the methods already explained, and the quantity of it expanded according to the indication of the barometer gauge.

Now, in number 3 of our tabulated experiments, we find that the barometer gauge fell from 21·3 in. to 6·3 in. in twelve minutes; this gives a leakage of 438·625 cubic feet of air of atmospheric density per minute, for by equation (Y), we have

$$\textit{leakage} = \frac{10527\,(30-15)}{30 \times 12} = 438{\cdot}625 \text{ cubic ft. per minute.}$$

Therefore, if this quantity be substituted for the symbol l in equation (AF), it becomes

$$\textit{velocity} = 56{\cdot}506 - \frac{121{\cdot}86}{30-h'};$$

then, if the observation be taken when $h' = 16$ in., the velocity corrected for the effect of leakage, is

$$\textit{velocity} = 56{\cdot}506 - \frac{121{\cdot}85}{14} = 47{\cdot}806 \text{ miles per hour.}$$

Mr. Stephenson makes the corrected velocity 50·4 miles per hour, but then, we may here remark, that the leakage per minute is taken at 345 cubic feet of air at the density of the atmosphere, and 738 cubic feet when expanded according to the degree of rarefaction, while the theoretical velocity is taken at 57·3 miles per hour; hence the difference between the results.—(*See* Table No. 4 of the Report, page 11.)

Since the above calculation has reference only to what takes place in the apparatus of the Kingstown and Dalkey Railway, it is necessary to direct the reader's attention to the general equation (AE), which will apply to any case, when the state of the gauge is known at two different observations, with the interval between them, as these data enable us to determine the quantity of leakage in one minute. The practical rule for reducing the equation (AE) may be thus expressed.

Rule.—*Calculate the theoretical velocity in miles per hour, by the rule to equation* (AB), *and reserve the result. Next calculate the leakage in cubic feet per minute at the density of the atmosphere; multiply this leakage by the constant co-efficient* 5500·395, *and divide the product by the difference between the standard height of the barometer gauge and the height at the time of observation, drawn into* 38 *times the square of the diameter of the valve tube: then, the quotient being subtracted from the theoretical velocity, will give the velocity corrected for the effects of leakage.*

Example 1.—In our tabulated experiments, No. 4, it will be found that the mercurial gauge descends from 22·3 in. to 5·7 in. in 14 minutes; what is the velocity in miles per hour when corrected for leakage, the average leakage per minute at the density of the atmosphere being 416·067 cubic feet, as calculated by the rule to equation (Y); the diameters of the air-pump and valve tube being 66·5 in. and 15 in. respectively, and the mercurial gauge indicating a height of 14·5 in.?

Since the diameters of the air-pump and valve tube are the same as before, it is manifest that the theoretical velocity must be the same also, namely 56.506 miles per hour; the first part of the calculation is therefore dispensed with in this case; and moreover, since the leakage per minute at the density of the atmosphere is also specified, the calculation of this element is likewise avoided. The remaining part of the process is therefore indicated by the term $\frac{5500{\cdot}395\, l}{88 d^2\, (30-h')}$, and is precisely what is described in the latter part of the rule; but since it is well adapted for logarithmic computation in consequence of the manner in which the quantities are combined, we shall reduce the expression in that way; the process is thus represented,

$$\log. x = \log. 5500{\cdot}395 + \log. l + \text{ar. co. } 2 \log. d + \text{ar. co. } \log. 88 + \text{ar. co.} \log. (30 - h'),$$

where the symbol x denotes the quantity to be found by calculation; the operation is as under,—

Constant co-efficient, 5500·395	log.	3·7403939	add.
Given leakage, 416·067 cubic feet	log.	2·6191633	
Diameter of tube, 15 in.	ar. co. 2 log.	7·6478174	
Constant number, 88	ar. co. log.	8·0555173	
Indication of the gauge, 14·5 in.; (30—14·5)= 15·5	ar. co. log.	8·8096683	
Natural number 7·4569 miles per hour, the retardation by leakage	log.	0·8725602	

Therefore, by subtracting this from the maximum theoretical velocity, we get $56{\cdot}506 - 7{\cdot}457 = 49{\cdot}049$ miles per hour for the corrected velocity. With Mr. Stephenson's constant leakage of 345 cubic feet per minute, and theoretical maximum velocity of 57·3 miles per hour, the corrected velocity, with 14·5 in. of vacuum, would be 51·12 miles per hour; for it is

$$\textit{velocity} = 57{\cdot}3 - \frac{0{\cdot}2778 \times 345}{30 - 14{\cdot}5} = 57{\cdot}3 - \frac{95{\cdot}841}{15{\cdot}5} = 57{\cdot}3 - 6{\cdot}18 = 51{\cdot}12 \text{ miles.}$$

This is a very important case, and is that which operates with the greatest force against the success of the atmospheric scheme: it requires the reader's most especial attention, and ought to be well understood. Mr. Stephenson has given a particular detail of its effects in page 12 of his Report, and seems to have been led by it to the most important of his conclusions in respect to velocity, and other points in reference to the probable advantages or disadvantages to be derived from the adoption of the atmospheric system of propulsion on railways.

In order that the young engineer may become familiar with the mode of calculating the correction for leakage, we propose the following examples for exercise in this particular case.

Example 2.—The diameters of the air-pump and vacuum tube being 66½ in. and 15 in. respectively; what will be the corrected velocity of the tube piston in miles per hour, with a vacuum of 17 in.; the length of tube receiving the leakage being 5923 ft., and the average fall of the mercury when the engine is quiescent, 1·46 in. per minute, the velocity of the air-pump piston being 253 ft. in the same time? Ans.

Example 3.—The diameters of the air-pump and vacuum tube, and the velocity of the air-pump piston remaining as in the preceding example; what will be the corrected velocity of the tube piston in miles per hour, the vacuum being 22½ in., the length of tube 3298 ft., and the average fall per minute 2·16 in.? Ans.

Example 4.—With a length of tube of 1435 ft., and an average fall of mercury of 3·37 in. per minute when the apparatus is at rest; what will be the velocity in miles per hour with a vacuum of 17 in., the diameters of the vacuum tube and air-pump, and the velocity of the air-pump piston being the same as before? Ans.

If these examples be resolved according to the formula and rule adapted to the purpose, it is presumed that the reader will be thereby so familiarized to the process, that no farther difficulty will present itself in cases of this nature, and by an attentive consideration of all the circumstances, a very correct and comprehensive idea of the effects of leakage may thus be obtained.

Seeing therefore, that the leakage of the apparatus exercises so great an influence in diminishing the velocity of the tube piston, and in consequence that of the trains attached to it, it becomes a matter of the greatest importance to get rid of this retarding influence as far as possible, either by diminishing the apertures of influx, or by a direct counteraction.

Several schemes have been devised for that purpose by ingenious individuals both in this country and on the continent, but all their endeavours have been directed to the improvement of the longitudinal valve, this being the source from whence the greatest portion of the leakage is derived. We are of opinion, however, that no species of valve will ever be invented that will completely remove this source of lost power and diminished velocity; inventors must therefore direct their attention to some other means, before they can expect their efforts to be crowned with success.

This has actually been done, for the invention of Messrs. Clarke and Varley dispenses with the longitudinal valve altogether, and promises in an eminent degree, to supply the very desideratum on which the success of the atmospheric system of propulsion must ultitimately depend. In their system, the great superiority of the merely lateral opening and closing of the tube over the longitudinal valve is most strikingly displayed, and this, combined with the further improvement of the metallic air-tight joint, precludes the desire of greater perfection in this novel and ingenious contrivance.

The main features of the scheme here alluded to, as being introduced by Messrs. Clarke and Varley, are the same as those employed in other cases where the atmospheric principle has been adopted, consisting of an arrangement of tubes, pistons, air-pumps, and steam engines; but here the similiarity terminates, for as we have already intimated, instead of having a permanent open slot, or aperture, running along the upper side of the tube throughout the whole of its length, and closed by a flexible flap, or valve, rendered partially air-tight by means of some unctuous composition manufactured especially for the purpose, the tube, or main, in which the exhaustion takes place, and in which the piston moves and carries forward the train, is constructed of sheet iron rolled to a proper thickness, and drawn into suitable lengths of sufficient width to answer the intended diameter of the tube.

These sheets, or plates of iron, being truly planed on the edges and chamfered to the proper angle, are then formed into tubes in the usual way, and are forced through dies to render them perfectly cylindrical; a form which induces a tendency to close, in consequence of the elasticity of the material, assisted by the external pressure of the atmosphere, so that the edges of the plates are brought together with a slight force, and form a perfectly air-tight cylindrical tube.

The method of opening this tube to admit the passage of the trains is very effective, and is simply as follows:—along the whole length of the tube, and on each side of it, supported on brackets pinned and keyed at proper intervals, are placed continuous bars of malleable iron, of sufficient strength and stiffness to resist the elasticity of the tube formed in the manner above described.

Attached to the leading carriage of every train is a frame of peculiar construction called the "Traveller," in which four rollers revolve in pairs, as shown in the following diagrams, and these rollers being a little wider than the bars are apart, force them open laterally, and in consequence of their connection with the tube on both sides of it, to whatever distance the bars are pressed outwards by the rollers, to the same distance must the tube be opened at the points where the rollers act; this allows a free passage to the coulter, or plate, which connects the piston within the tube with the traveller on the outside; and consequently, as the pressure of the atmosphere behind the piston carries it onwards against the vacuum before it, it must carry the train along with it; when the traveller and rollers have passed, the tube closes by its own elasticity, and becomes again in a fit condition for another exhaustion.

The mode of operation however, will be readily understood by reference to the annexed drawings.

FIG. 1.

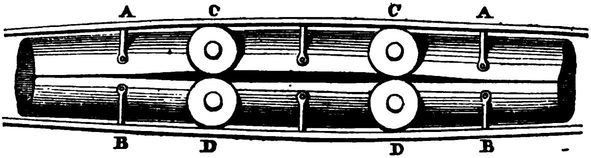


Fig. 1, is a plan of the tube and side bars, showing the manner in which the opening is effected by the rollers, and maintained of sufficient extent behind the piston, to admit a quantity of air of atmospheric density to supply the vacuum, and carry the piston forward, independently of the air that travels along the tube, or main, agreeably to the simple laws of nature.

Fig. 2, is a transverse vertical section through AB Fig 1, showing the manner in which the side bars are supported by brackets rivetted to the tube, which is here represented as having the longitudinal opening, or aperture that admits the passage of the coulter, closed.

FIG. 2.

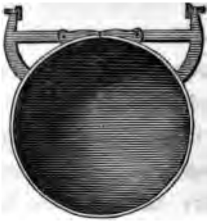
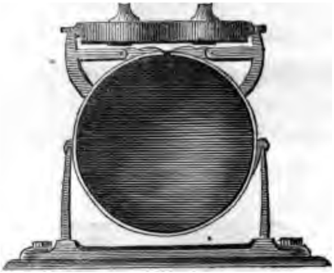


Fig. 3, is a transverse vertical section through the tube and rollers at CD, showing not only the mode of connection, but the manner in which the rollers operate on the side bars to press them asunder, and by this means to open the longitudinal aperture along the upper side of the tube; this opening is distinctly indicated in the figure, where it will be seen that the rollers working in contact with each other, must in a great measure annihilate the friction on the axles, in consequence of the equal and opposite resistance of the side bars.

The same section also shows the manner in which the tube is connected with the transverse sleepers, and by being supported on standards as represented in the drawing, it will at once be perceived that the tube will have a tendency to close on the upper side by means of its own weight, thus securing a perfect coincidence of the edges of the opening, independently of the elasticity of the material and the pressure of the external air.

FIG. 3.



The figures 4 and 5 give a representation of the new metallic air-tight joint; Fig. 4 is a full sized section where the ends of two segments of the tube come together, showing the copper ridge for admitting the free expansion and contraction of the tube, and the manner in which it is rendered air-tight. In this joint the two flat sides, or flanges, of the copper ridge, are bound to the tube by iron straps or collars, and keyed fast up to the longitudinal opening, thereby forming a perfect metallic tube, without the aid of leather, vulcanized India rubber, grease, or any other perishable material whatever.

FIG. 4.

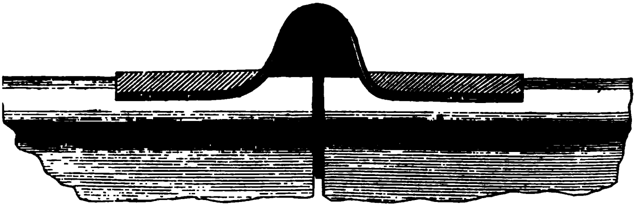
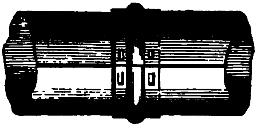


FIG. 5.



When the tube is constructed in this manner, nothing in the working of a railway can affect it; time, oxidation, and vibration from passing trains are alike harmless; subsidence of the sleepers has little or no influence on the tube, and in every case where it is applied the trains must proceed with regularity, certainty, safety and comfort; and with regard to speed, there can be no doubt that under this arrangement, where the retarding effect of leakage is removed, a much higher velocity may be attained than can ever, under any circumstances be reached by a locomotive engine, even of the best possible construction.

With these improvements, and the experience which has now been gained in working the apparatus, we may reasonably expect, that notwithstanding the partial failure that has hitherto attended the application of the atmospheric principle, it will nevertheless, at no very distant period, be brought into full operation, and supersede every other system of railway transit that has hitherto been suggested.

We cannot close this essay on atmospheric propulsion, without adverting to some remarks suggested by Mr. George Medhurst, Civil Engineer, of Denmark Street, Soho. As long ago as 1812, he says :—

"The principal advantages attending this mode of transit will be,—Passengers may be conveyed to the greatest distance through the country with ease and safety at the rate of a mile in a minute, or 50 miles per hour upon an average, and at the expense of one farthing per mile.

"All kinds of portable goods, merchandise, manufacture, and produce, will be conveyed with the same velocity, and at the expense of one penny per ton per mile.

"The conveyance cannot be obstructed or impeded by frosts, snow, floods, or drought, nor endangered by robbery, by darkness, or the weather.

"No locks or other obstructions will be required in the passage, for the force of the impelling air will be sufficient to gain an ascent of 100 feet in a mile continually.

"Artillery, troops, baggage, and stores, may be conveyed with the same rapidity, safety, certainty and expense : and live cattle will be enabled to pass through the country without labour, and at a very small expense for carriage or for food.

" Fish may be brought from the coast in a perfect state, and all perishable goods will be brought to market from their native soil, and in their native purity,

" And the mails may be conveyed at a very small expense; for the weight of 200,000 letters will not exceed one ton, and they may be delivered twice a day at 400 miles distance.

How far these anticipations have been realized by recent operations, the public is now enabled to decide.

Answers to Unresolved Examples.

Ex. 2, *p.* 10—Density after 15·5 strokes of the air-pump; 0·2122 of the unit.

Ex. 3. ,, Density after 32·5 strokes or descents of the piston, 0·127 of the unit.

Ex. 4. ,, Density after 2½ strokes, 0·063; density reduced 0·562 of the unit.

Ex. 2, *p.* 13—The air is rarified 2½ times for an indication of 19 inches.

Ex. 3, ,, The air is rarefied 5·8 times for an indication of 24 inches.

Ex. 4, ,, The air is twice rarefied for an indication of 14 inches.

Ex. 2, *p.* 15—The barometer gauge will indicate 26 in. when the air is rarefied 7½ times.

Ex. 3, ,, The gauge will indicate 23·6 in. when the air is rarefied 5 times.